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A STUDY OF THE DISTRIBUTION OF NATURALLY OCCURRING RADIONUCLIDES IN FRESHWATER BENTHOS AND THEIR ENVIRONMENT PHASE I REPORT

FINAL REPORT

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1.0 INTRODUCTION

1.1 Project Summary

To evaluate the potential impacts to man of the uranium series radionuclides released by uranium mining and milling activities to surface water systems, it is necessary to be able to predict resulting levels in various media through which individuals may receive exposure. Exposure may be external (i.e. resulting from direct exposure to elevated levels of radionuclides in water, sediments or shorelines) or internal (i.e. resulting from the ingestion of water, aquatic plants or aquatic organisms such as clams or fish). Further exposure could also result through the agricultural use of surface waters. Figure 1.1 illustrates the possible pathways involved.

Unfortunately, the environmental transfer factors are among those parameters which are the most variable and which display the most uncertainty in the estimation of exposure. This report is part of a program directed towards developing a better understanding of the role of benthic communities in this larger network of exposure pathways (see the shaded area in Figure 1.1).

The stated objectives of this study for the National Uranium Tailings Program (NUTP) are:

1. To determine the distribution of key uranium series radionuclides between water, sediment and the associated benthic communities.
2. To calculate distribution coefficients and bioconcentration factors for these organisms and water, and these organisms and sediments.

To accomplish these objectives, the study has been split into two phases. Phase I involves a critical review of the currently

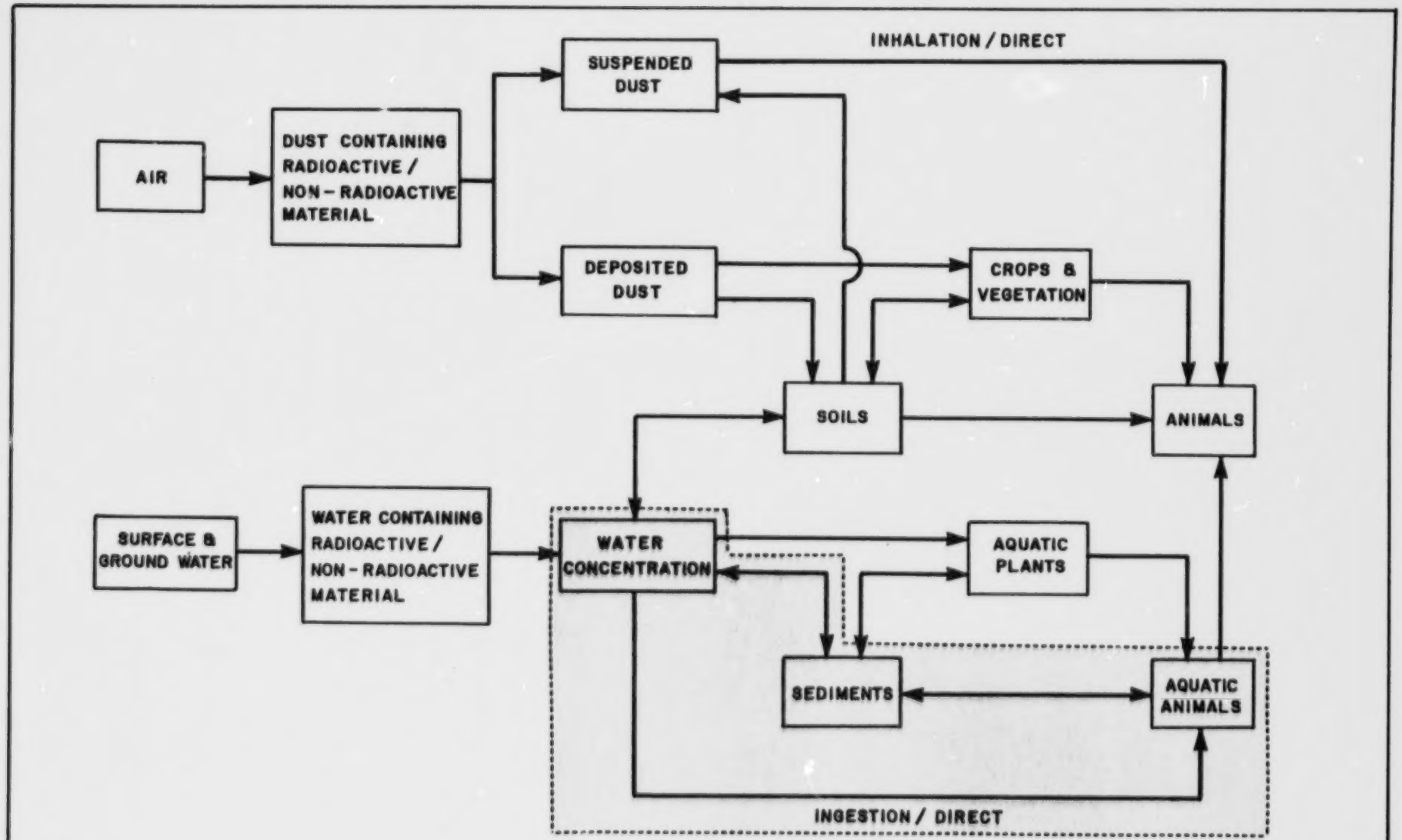

FIGURE 1·1

EXPOSURE PATHWAYS FOR BIOTA

available information. Phase II will involve field and laboratory studies most appropriate to resolving those deficiencies in the data that most directly relate to the objectives of the NUTP.

To meet the objectives of the study as outlined above, a number of tasks were defined for Phases I and II. These tasks include:

PHASE I - CRITICAL LITERATURE REVIEW

1. To review currently available studies on distribution coefficients and bioconcentration factors for key uranium series (and thorium series) radionuclides for benthic communities and water, and benthic communities and sediments. (See below for a discussion on the selection of key radionuclides.)
2. To gather available data on the distribution of these radionuclides in water, sediments and benthic communities.
3. To critically evaluate the data gathered in 1 and 2 in order to synthesize what is currently known about aquatic concentration factors for uranium (and thorium) series radionuclides and to identify deficiencies in this data.
4. To identify which deficiencies in this data base are the most significant in terms of potential dose to man in order to set priorities for further studies in Phase II.
5. To identify the operational problems that would affect the design, execution and evaluation of Phase II. These would include sampling problems, analytical aspects, costs, and the ability to meaningfully interpret the results as they apply to the objectives of NUTP.
6. To design (in co-operation with the Scientific Authority) the optimal Phase II program, based on the above and time and cost restraints.

PHASE II - FIELD INVESTIGATION

1. To execute the field program designed in Phase I in a manner that will ensure meaningful results, proper documentation and cost effectiveness.
2. To interpret the resulting data and calculate distribution coefficients and bioconcentration factors as appropriate.
3. To evaluate the implications of this new data in terms of the importance of the related food chains in the exposure of man.

This report documents the results of the first four tasks of the Phase I studies.

1.2 Bioaccumulation Factors and Distribution Coefficients

1.2.1 Definition

Radionuclides entering the freshwater environment are subjected to a number of competing processes, as illustrated in Figure 1.1. One of these processes is uptake by benthic organisms, either by adsorption or absorption. The benthic organisms thus become part of a food chain through which radionuclides may eventually reach man.

Many of the models that simulate the movement of radionuclides from a source through food chains to man are equilibrium models, i.e. steady state conditions are assumed to have been reached. This assumption applies to long-term waste management situations such as uranium tailings.

Bioaccumulation factors (BF's) are used in these models to specify the degree of transfer of a radionuclide from water to benthos, or in some cases, sediment to benthos. Bioaccumulation

factor are the ratios of the radionuclide concentrations in the benthos to the radionuclide concentrations in water (or sediment). BF values pertaining to water are usually expressed in units of kg/L or g/mL (care must be taken to identify the exact units to be used) while those for sediment are expressed in units of g/g.

In some modelling situations, the transfer of radionuclides to the sediment may be represented by a distribution coefficient: the ratio of the radionuclide concentration in sediment to that in water (L/kg). Although the emphasis of this study is not on water-to-sediment interaction, a review of this phenomenon has been included to better understand the potential role of benthos/sediment interactions in the food chain and to give some additional basis for assigning priorities to the goals of the Phase II field program.

1.2.2 Factors Influencing the Variability and Use of Bioaccumulation Factors

Many factors can influence the BF's reported in the literature. It is important to recognize the significance of these factors particularly as they may influence the suitability of a BF for any given modelling situation. The following is a brief summary of such factors (Blaylock 1982, Zach 1980), and is presented here because of its usefulness in designing the Phase II field program.

Equilibrium Assumption

As stated above, BF's are used in models where a steady state is assumed to have been achieved. Ideally then, BF's should be determined under equilibrium conditions, i.e. the benthos has been in a freshwater environment (which must be in equilibrium

itself) for a long enough period to achieve equilibrium.

Seasonal Trends

Some BF's may vary on a seasonal basis. If BF's are to be applied properly, it is necessary to have some feeling about the seasonal versus annual role of the benthos in the food chain and to subsequently select the most appropriate BF. Conversely, a BF that is based on one season's data may not be appropriate for annual modelling.

Linearity

A basic assumption in the determination and use of BF's is that they are constant regardless of water or sediment concentrations. In reality, BF's can vary greatly with environmental parameters. Unfortunately, there is insufficient data to allow use of environment-specific BF's.

Wet Weight and Dry Weight

Several different types of weights for the benthic (or sediment) radionuclide concentration have been used in calculations of BF values. These include wet weight (or fresh weight), dry weight and ash weight. BF's based on dry weight of benthos are higher than those based on wet weight, and BF's based on ash weight are higher again. Conversion factors used to change dry or ash weight to wet weight must be chosen with care.

Analytical and Sampling Error

The analytical accuracy of BF's is seldom reported, and is difficult to assess. Sampling errors (aside from program design errors) are also difficult to assess. Sampling errors can

include taking water or sediment samples that are not representative of the environment from which benthos were collected.

Filtered and Unfiltered Water

BF's may be based on filtered or unfiltered water samples. A significant fraction of some radionuclides may be in the suspended phase in water. Thus BF's based on filtered water samples will be higher than those based on unfiltered water samples. For environmental modelling, unfiltered samples are desirable.

Tissue Distribution

BF's for benthos may be based on an analysis of the whole organism, or be specific to certain soft or hard tissues. To maximize the usefulness of field data for modelling purposes, it is important to analyse those portions of the organism that will be passed along the food chain.

Chemical State of the Radionuclide

Radionuclides exist in a wide variety of physicochemical forms in freshwater environments, each form having a different availability to benthos. Very little data exists to explain how this may affect a BF for any particular radionuclide. This is discussed in more detail in later sections.

Chemical Composition of the Water and Sediment

The presence of other minerals, compounds and ions can strongly influence the behaviour of radionuclides in the freshwater environment. This is discussed in more detail in later sections.

Feeding Habits of Organisms

Benthic-feeding organisms may be exposed to high concentrations of radionuclides that have accumulated in the sediments. Therefore the gut contents of benthos can significantly influence the whole body BF, and cause large variability for benthic feeders even within one location and common environment.

1.3 Selection of Key Radionuclides

The following radionuclides were chosen for the Phase I literature review, based on their presence in uranium tailings and their potential significance in dose-to-man assessments:

- Uranium
  - total uranium
  - natural uranium
  - U-238
  - U-234
  - U-235
- Thorium
  - total thorium
  - natural thorium
  - Th-230
  - Th-232
- Radium-226
- Lead-210
- Polonium-210

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2.0 URANIUM

2.1 Distribution in the Freshwater Environment

Uranium, atomic number 92, is a radioactive metal of the actinide series and a member of group IIIB in the periodic table of elements. It is also referred to as being one of the primordial radionuclides, having been present since the earth's formation. The uranium isotopes found normally in nature are U-234, U-235, and U-238. These isotopes all decay primarily by alpha emission; their half-lives are 2.4×10^5, 7.0×10^8 and 4.5×10^9 years, and their isotopic abundances are 0.0054, 0.720 and 99.2746 percent, respectively (Sheppard 1980). Uranium-238 is the parent of the uranium decay series; uranium-235 is the parent of the actinium decay series (Eisenbud 1973).

Uranium-238 is the most abundant of the three isotopes and is the primary focus of the following discussion. Since the other isotopes of uranium behave very similarly chemically, the discussion is also pertinent to them.

Uranium exists in four valence states: U^{3+}, U^{4+}, U^{5+} and U^{6+}. Only the tetravalent (4+) and hexavalent (6+) states are commonly found in nature. Hexavalent uranium is invariably associated with oxygen as the very stable divalent uranyl ion (UO_2^{2+}) and occurs whenever oxidizing conditions are present. Tetravalent uranium is found in reducing environments.

The uranyl ion has the properties of a large, simple, doubly-charged metallic ion. It tends to form compounds such as $UO_2(OH)_2$, UO_2CO_3 and UO_2SO_4 (Sheppard 1980). Carbonate and bicarbonate complexes of uranium are very soluble; therefore, uranium concentration in water is strongly correlated with alkalinity (R.E.C.S. 1978, Dyck 1974). In carbonate-free water,

uranium oxide and hydroxide complexes predominate, although phosphate, fluoride, sulphate and silicate complexes can also occur (Sheppard 1980).

The hydrolytic tendencies (tendency to be complexed by OH^-) of metal ions are an important aspect of their aqueous chemistry. Uranyl ions are less hydrolytic than many of the other actinides (thorium, plutonium, americium). The tendency of these elements to form complexes with organic and inorganic ligands follows the same order. What this means in the environment is that the uranyl ion, being less hydrolytic than, for example, thorium, tends to remain in solution while the more hydrolytic Th cation readily sorbs to abiotic and biotic surfaces and is removed from the water column (Dahlman et al. 1976).

In general, investigation of uranium loss from surficial environments, leaching experiments, isotope analysis and disequilibrium studies all indicate that uranium is the most mobile non-gaseous element in the uranium decay series (Dyck 1975).

The concentration of uranium in sediments is affected by several factors including: the solubility of uranium complexes, the presence of iron and manganese oxides, amount and type of organic material, sediment texture and redox potential.

Relatively insoluble uranium compounds can result from complexation of uranium in low-carbonate waters. Phosphate uranium complexes are exceedingly insoluble and precipitate out of solution readily, as do potassium uranium complexes (Langan 1983). Analysis of soils in the Soviet Union has shown that the total uranium content correlates with the oxides of silicon, iron and aluminum, suggesting coprecipitation or inclusion (Yakobenchuk 1968).

Enrichment or depletion of uranium in soil or sediments is influenced by oxides of iron and manganese. These oxides reduce uranium from U^{6+} to U^{4+} (Megumi and Mamuro 1977). The tetravalent uranium ion has a high affinity for organic material and thus can be quickly removed from solution via adsorption.

Organic matter is often the most important single variable influencing uranium content in sediments (Dyck 1974). Organic matter strongly complexes uranyl ions and also may serve as a reducing medium. Algal mats, humic acids and other organic substances in natural waters fix uranium and eventually fall to the bottom to form sediments (Langan 1983). Organic muds, black shales and decaying organic matter have been found to concentrate uranium to 350 ug/g (Koczy 1963). Humic acids have been found to be very powerful sorbers of uranium; the sorption is a cation exchange process related to the carboxylic groups present in the acids (Szalay 1964). Complexes of fulvic and humic acid polymers accounted for a significant portion of uranium in sediments studies by Sheppard et al (1980).

Adsorption onto sediment particles is related to particle size (ie. sediment texture). Adsorption generally increases with decreasing particle size. The mechanism of adsorption is primarily cation or base exchange. Since the uranium ion has a very large radius it would be expected to adsorb by base exchange onto clays and other lattice minerals, including skeletal bones, invertebrate shells and teeth of living and dead organisms (Langan 1983, Sheppard 1980). The configuration of the uranyl ion allows it to form a strong structure when adsorbed. This arrangement provides considerable resistance to mobility, particularly when adsorbed between layers of carbonaceous material (Sheppard 1980).

The redox potential greatly affects solubility and mobility of uranium. Under oxidizing conditions it forms soluble complexes. Under reducing conditions the tetravalent ion forms complexes that are much less soluble (PO_4^{3-}, CO_3^{2-}, etc.) or adsorbs strongly to organic material (Sheppard 1980).

Once deposited onto sediments, uranium can be re-distributed by physical, chemical and biological phenomena. These include physical transport of sediment particles by lake currents or streamflow, sorption-desorption phenomena at the sediment-water interface in lakes, and cycling through food chains.

The general ecological properties of uranium include: a chemical analogue of sulphur and perhaps selenium; primary exposure modes through ingestion, inhalation or external gamma irradiation; a low-to-moderate degree of food chain transport; a successive trophic level concentration of less than 1.0, critical accumulation in the kidney, lung and gastro-intestinal (GI) tract; a very low degree of assimilation; and a moderate (in the order of months) biological half-life (Whicker and Schultz 1982).

Uranium is considerably more mobile in biological systems than thorium or radium (Whicker and Schultz 1982). Therefore, since it is taken up by biota at the base of a food chain, it tends to have higher transfer coefficients from one trophic level to another than other nuclides. This has been reported in the foodchain studies (sediments-insects-forage fish-whitefish) of the Beaverlodge area, Saskatchewan (Swanson 1984).

Because the environment behaviour of uranium (and other nuclides) is strongly influence by site-specific conditions a firmer basis than the foregoing generalizations is needed to confidently make quantitative predictions.

2.1.1 Uranium in Fresh Water

Concentrations of uranium in surface water are commonly a few micrograms per litre and rarely exceed 10 ug/L (Langan 1983). Uranium levels are naturally higher near ore deposits, especially where the bicarbonate content of the water is high. Elevated levels of uranium have been observed in lakes and streams receiving effluent or drainage from uranium mine, mill or waste management areas in the Wollaston, Beaverlodge and Cluff Lake areas of Saskatchewan and the Elliot Lake and Bancroft areas of Ontario (Table 2.1). Other activities that contribute to the levels of uranium in water include the use of uranium compounds in photographic toners, pigments and glazes, combustion of uranium-containing organic fuels (coal and petroleum), the roasting of sedimentary rocks for cement production, and the use of phosphate fertilizers containing uranium complexes (Langan 1983).

The concentration and behaviour of uranium in water is affected by many water quality parameters. Some of the more important factors include total dissolved solids (TDS), pH and alkalinity. The uranyl ion readily forms soluble salts with many commonly occurring anions, therefore, TDS can directly affect uranium levels. The behaviour of different uranium species in solution is also influenced by pH. For example, uranium oxides and their hydrolysis products have the highest solubility at pH values in the range of 4 to 6, while at higher pH values, the uranyl ion forms soluble complexes with carbonate ions (Langan 1983). Uranyl carbonates commonly contribute significantly to uranium concentrations in water. Decreases in CO_2 concentrations may result in uranium precipitation, while an increase in alkalinity may enhance its solubility (Taylor 1979).

In addition to considering water quality parameters, uranium

levels should be related to seasonal and annual fluctuations, which in turn result in changes in food chain uptake.

2.1.2 Uranium in Freshwater Sediments

Sediment data for uranium are voluminous, because of the use of lake sediment surveys for uranium exploration. For example, the Nuclear Energy Agency/International Atomic Energy Agency Athabasca Test Area in Saskatchewan has been thoroughly sampled for water, sediments, soils and vegetation in an 1200 km^2 area (Cameron 1983). Exploration data are not included in this report because of the magnitude of the database; instead, academic and impact assessment reports have been summarized, with emphasis on work that includes matched water, sediment and benthos data.

Freshwater sediments commonly contain 1 to 5 mg/kg uranium (Langan 1983). Sediments near uranium ore bodies can contain 100 to 700 mg/kg uranium or more (Langan 1983, Coker and Dunn 1983, Table 2.1). Similar uranium levels occur in sediments downstream of uranium mill tailings management areas, eg. Hidden Bay of Wollaston Lake, Beaverlodge Lake, Langley Bay (Table 2.1).

Important parameters to include with uranium sediment data are organic content and texture (see 4.1).

2.1.3 Uranium in Benthos

There is very little information on uranium uptake by benthic invertebrates. Thompson et al (1972) suggest an average concentration in the tissues of freshwater benthos of 0.1 mg/kg. Existing data indicate that anthropogenic activity can cause increased levels of uranium in benthos. This can be seen in the Elliot Lake and Beaverlodge data (Table 2.2). Very high uranium levels were found in caddisflies (Trichoptera) and amphipods

(Gammarus) in a Yugoslavian stream polluted with uranium mine water (Stegnar and Kobal 1982).

The limited data available show that sample variation is high. This reflects the large number of factors that can affect uranium concentration in benthos, including life stage, longevity, mobility, physiology, food and habitat preferences. More data are required before "representative ranges" of uranium concentrations can be derived for specific groups of benthic invertebrates.

2.2 Aquatic Concentration Factors

2.2.1 Distribution Coefficients - Sediment to Water

Distribution coefficients, or $K_{d's}$, are a means of illustrating the relative radionuclide concentrations in water and sediment. They can be used as a short-hand description of the sorptive capabilities of the sediment in a given environment.

Very few examples of uranium K_d's appear in the literature. In general, uranium in the uranyl ion form is not removed to the sediments to the same extent as tetravalent species of either uranium or other actinides (Dahlman et al. 1976). Sediment particles in the 2 to 60 nm range account for much of the adsorption of uranium. The important smaller particles (2 to 3 nm radii) are complexes of humic matter; larger particles (10 to 60 nm) are usually clay (Sheppard et al. 1980). Sorption sites are on the surfaces of the particles.

The uranium content of Beaverlodge area stream sediments was found to be related most strongly to the presence of organic (humic) matter (Dyck 1974). Uranium in soils from the Oak Ridge, Tennesse area has shown a preference for the somewhat larger clay

particle fraction (Sheppard et al 1980). Although K_d's specific to uranium are very rare in the literature, authors agree that K_d's for any radionuclide should be related to the particle size of the sediment being studied.

Uranium K_d's from Beaverlodge Lake, the Tailings Creek system and two control (uncontaminated) lakes in northern Saskatchewan are very variable (Table 2.3). Control K_d's are higher than those from contaminated areas, reflecting a trend noted for bioaccumulation factors, ie. higher uptake at low environmental concentrations. The relationship with particle size is most obvious when Tailings Creek sandy sediments are compared to the clay-silt sediments common in the lakes; the sandy sediment particles retain far fewer uranium ions (Table 2.3). The uranium K_d's are lower than those noted for radium-226 (Table 4.3) illustrating the greater tendency for uranyl ions to remain in solution.

2.2.2 Bioaccumulation Factors - Water to Benthos

There is a great lack of data on uptake of any of the uranium series nuclides by benthic invertebrates. The few data that do exist show that uranium BF's for most species may be in the range of 100 to 1000 (Table 2.4). Data from the Beaverlodge area show BF's in the 500 to 1000 range for uncontaminated areas; these are somewhat higher than those reported in Thompson et al (1972). Uptake in contaminated areas is much lower (<1.0 to 7.0). This phenomenon may be due to low essential nutrient levels in uncontaminated systems, resulting in greater relative uptake of all elements. Since uranium is an analogue of sulphur, its uptake may be linked to sulphur levels in water (Whicker and Schultz 1982). It is obvious, even from the few data presented here, that the use of a single "representative" BF for uranium in invertebrates, without reference to site-specific water

chemistry, can result in large errors in pathway analyses.

The uranium BF's in Table 2.4 also vary among species; however, variation is not as pronounced as it is for radium-226 or lead-210 (Swanson 1984). Uptake from water is likely to be primarily via respiration. The relatively uniform BF's among species may reflect similar demand for, and uptake of, uranium across respiratory membranes.

2.2.3 Bioaccumulation Factors - Sediment to Benthos

Although uranium is one of the more soluble radionuclides, the greater proportion is still usually found in the sediments (see Section 2.2.1). Therefore, sediment-benthos BF's are more useful for prediction of pathway transfer of uranium. To date, sediment-benthos BF's are extremely rare.

Existing data show that sediment-benthos BF's for uranium are relatively low (0.1 to 2.1). Low BF's may indicate that uranium uptake from sediments is via passive modes such as ingestion of particles or adsorbtion to integuement, rather than active processes linked to uptake of essential nutrients across respiratory membranes. High uranium levels in caddisflies and Gammarus in a Yugoslavian stream were attributed to adsorption to organic receptor sites on invertebrate exoskeletons (Stegnar and Kobal 1982). Relative uptake of uranium from sediments in a waste-water pond was related to extractability (using nitric and hydrochloric acid) of the uranium (Garten et al. 1981). This latter study showed that habitat, in particular the degree of association of an organism with the sediment-water interface, was the primary factor controlling actinide (including uranium) levels in aquatic biota.

Sediment-benthos BF's in Table 2.4 do not show the variation with

site or species noted for water-benthos BF's. This may reflect more passive, non-specific modes of uptake from sediment.

More data are required before variability of sediment-benthos BF's can be assessed and related to important sediment-type and biological parameters.

2.3 Deficiencies in the Data Base

The deficiencies outlined below are common to all the nuclide databases considered in this report.

1. The lack of uniform, standard sampling techniques for sediments and benthos produces uncertainty when comparing data from different studies. It is important that techniques be fully described so that when the data base enlarges, optimum techniques can be chosen based on replication and comparison of sample variation. It is also important to use standard, comparable units (eg. Bq/g wet weight).

2. Replication is necessary for an adequate data base. Because sediments can vary greatly even within small areas, and because of idiosyncracies of sampling devices, what may appear to be significant trends in the data may be due to sampling error. Future work must include sufficient replication to eliminate this uncertainty.

3. Proper support data must be collected to help explain observed trends. Important sediment parameters include texture, percent organic content, iron and manganese levels. Physical characteristics of the environment should also be noted, for example, mean depth of the lake being studied, current velocity in streams and water temperature. Since

little is known about uranium dynamics in ecosystems, it is important to collect supporting chemical, physical and biological data.

4. Sediment-benthos or water-benthos data are most useful when the invertebrates are properly identified (at least to genus). Lumping benthos into families or orders has little or no meaning for radioecological studies due to variation in physiology, habitat and feeding habits of individual species. To date, most data are deficient in this regard.

5. If benthos data are to be useful for modelling food chain transfer to man, the benthos being studied must indeed be consumed by organisms in critical pathways. Existing data are usually for invertebrates that are common and easy to collect. It is likely that these invertebrates are important food items, but data are needed to pursue this, and to differentiate which species can best be used as indicators for critical pathways.

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TABLE 2.1

A REVIEW OF URANIUM LEVELS IN SEDIMENT AND WATER

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Beaverlodge, Sk.	June to Aug/1969	-	ppm	5.10*	-	ppb	0.50*	Dyck 1974
		-	ppm	7.0*	-	ppb	1.0*,1.1*,0.9*	
					-	ppb	1.0*,1.0*,1.0*	
					-	ppb	0.8*	
Ace Creek, Sk	June/76				-	ug/L	100,36,20	Ruggles and Rowley 1978
	Sept/76				-		9.7,345	
Beaverlodge L., Sk.	Jun /76				-		200,520,197	
	Sept/76				top		575,214	
Fredette L, Sk.	June/76				-		6	
Tailings Cr., Mouth, Sk.	June/76				-		2340,2460	
	Sept/76				-		2065	
Greer Lake, Sk.	June/76				-		2260	
	Sept/76				-		1910	
Meadows Dam, Sk.	June/76				-		2690	
Treated Mine Water	Jun /76				-		6530	
Fay Mine Water	Jun./76				-		8000	
Tailings Cr. Below Marie L. Dam	June/76				-		2180	
Marie Lake, Sk.	June/76				-		2220,2220	
Fookes Lake, Sk.	June/76				-		2490	
Tailings Creek, Sk.	June/76				-	ug/L	2455,2340	
					-		2444,2260	
					-		3082,2690	
	Sept/76				-		2515	
					-		2060,1980	
Ace Creek, Sk.	June/76				-		1050	
					-	ug/L	20,26,21	
	Sept/76				-		36	
					-		45,90,27	
					-		9.7,390	
Nero L, Sk.	June/76				-		257,214	
Jean L, Sk.					-		879,850	
					-		156,170	
Elliot L, Ont. Sta. 1	1977				-	ug/L	198	Moffett and Tellier 1977
Sta. 2							158	
Sta. 3							230	
Sta. 4							475	
Sta. 5							260	
Sta. 6							600	
Sta. 8							190	
Sta. 14							35	
Sta. 16							78	
Sta. 7							2000	

* mean value

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Sediment Sample Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Sta. 9	1977				-	ug/L	38	Moffett and Tellier 1977 cont'd
Sta. 10							110	
Sta. 11							6900	
Sta. 12							30	
Sta. 13							39,800	
Sta. 15							25,400	
Sta. 17							120	
Sta. 18							5200	
Sta. 19							370	
Sta. 20							170	
Precipitation Pond								
Effluent, Rabbit L. Sk	1977				-	ppm	1.9*	Robinson et al 1983
	1978				-		2.6*	
	July/78				-		1.2,1.5,1.4	
Effluent Cr. System	July/78				-	ppm	0.14,0.10,0.15	
							<0.06,0.06	
							<0.06,<0.06	
							<0.06	
Hidden Bay	July/78				-	ppm	<0.06,<0.06	
							<0.06	
Rabbit Creek	July/78				-	ppm	0.23	
Pow Bay							0.06,<0.06	
							<60, 1.6	
Parks Creek					-		<0.06	
Collins Cr.							0.08	
Horseshoe L.	Dec/72				-	ppb	5	
	Nov/76				-	ug/L	2.2	
	1978				-		1.22*	
	July/78				-		0.15	
	July/78				-		<0.06	
Effluent Cr.	July/78				-	ppm	3.9,128,159,	
							225,14.4,12.4	
							177,18.7,33.1	
							21.3,28.2,47.2	
							3.2,1.5	
Hidden Bay	July/78				-	ppm	20.9,19.9,	
							5.9,6.3,2.1	
Rabbit Cr. System							2.3,1.8,175	
							204,167,898	
							899,441,1140	
							1430,3280	
							3460,3190,	
							3010,2960	
							2990,1230,1720	
Pow Bay Tailings (dewatered)					-	ppm	11.3,5.9	
							76	

*mean value

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Ishikari R., Japan	1961					10^{-6}gm/L	0.41	Miyake et al 1964
Mogami R., Japan							0.38	
Kitakami R., Japan							0.65	
Shinano R. Japan							0.58	
Tone R., Japan							0.62	
Kiso R., Japan							0.58	
Yodo R., Japan							0.34	
Yoshino R., Japan							0.77	
Asaki R., Japan							0.67	
Chikugo R., Japan							1.23	
Too Small L., Sk.	1979					ug/L	<0.5*	Canada Wide Mines 1981
McClean L, Sk.	1979						<0.5*	
Collins Bay, Sk.	1979						<0.5*	
Langley Bay, Sk.	July/78							
Sta. 1		-	ug/g	489,35,405				Ruggles et al
Sta. 2		-		55,524				(unpublished) 1978)
Sta. 3		-		69.9,66.2,50				
Sta. 4		-		452,376				
Lake Athabasca, Sk.,								
Sta. 5		-		199				
Sta. 6		-		25.7				
Sta. 7		-		3.3,3.1				
Nero L, Sk Sta.5	June/76	-			-	ug/L	850	
	Sept/76	-			-		1250	
Beaverlodge, Sk. Sta. 9	June/76						240	
	Sept/76						900	
L. Athabasca, Sk. Sta. 5	Sept/76				surface		3	
Langley Bay, Sk. Sta 2	June/76				-		10	
	Sept/76				-		4	
Gunnar open Pit Discharge Sta. 8	Sept/76				-		490	
Nero L. Sk.	1978					ppm	0.76*,0.81,0.76* 0.76*,0.78,0.74	
Wollaston L. Area, Sk.								
S-0 Dnst. of Airport Rd.	Aug/81	-	ug/g	819				Gulf Minerals Canada Ltd.
S-1 Sedimentation Dam	Aug/81	-		1195				1981, Environ. Sask.
	Apr/81	2080						Monitoring Data 1982
S-2 Pow Bay	Aug/81	-		23.5				
S-3 Horseshoe L.	Apr/81	-		164				
	Aug/81	-		407				
S-4 Hidden Bay	Aug/81	-		47.6				
S-5 Parks L. at n. end	Aug/81	-		7.1				
S-6 Inflow Delta to Pow Bay	Aug/81	-		31.3				

*mean value

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Boulder Cr., Sk.	Nov/80	-	ug/g	3.6				(Amok 1980) Environ. Sask. Monitoring Data 1982-83
Snake L, Sk.				0.8				
Cluff L, Sk.	June/81	-	ug/g	11.0				(Amok 1981) Environ. Sask. Monitoring Data 1982-83
	Nov/81	-		35.9				
Snake L, SK	June/81	-		2.0				
	Nov/81	-		2.6				
Boulder Cr., Sk	June/81	-		57				
	Nov./81	-		53.5				
Island L., Sk	June/81	-		3.0				
	Nov/81	-		7.7				
Rabbit L, Sk.								
S-1 Sedimentation Pond	Aug/80	-	ug/g	2700				(Gulf Mineral Canada Ltd. 1980) Environ. Sask. Monitoring Data 1982-83
S-2 Pow Bay		-		4.4				
S-3 Horseshoe C.		-		260				
S-4 Hidden Bay		-		50				
S-1 Sedimentation pond		Core tube	ug/g					
		0-2 cm		5650				
		2-4 cm		1890				
		4-6 cm		464				
		6-8 cm		328				
		8-10 cm		307				
		10-12 cm		191				
		12-14 cm		196				
		14-16 cm		149				
		16-18 cm		123				
S-2 Pow Bay		0-2 cm		9.1				
		2-5 cm		3.3				
		5-10 cm		2.8				
		10-15 cm		1.8				
		15-20 cm		2.3				
S-3 Horseshoe Bay		0-4 cm		53.5				
		4-6 cm		3.2				
		6-8 cm		2.0				
		8-10 cm		1.7				
		10-12 cm		1.6				
S-4 Hidden Bay		0-2 cm		167				
		5-10 cm		36				
McDonald Cr. Sk.	1982	dry	ug/g	4.3				(Key Lake 1982) Environ. Sask. Monitoring Data 1982-83
David Cr. Sk				0.8				
Delta L, Sk				0.4				
Russell L, Sk.				1.5				
Little McDonald Cr. Sk.	July/77			169				
	Oct/78			160				
McDonald Cr. Sk.	July/77			62.7				
	Oct/78			23				

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Outlet Cr.	Aug/77		ug/g	5.3				(Key Lake 1982) Environ. Sask. Monitoring Data 1982-83
	Sept/78			0.14				
David Cr. Sk.	Sept/78			0.16				
Boulder Cr. Sk.	M y/83	-		47.0				(Amok 1983) Environ. Sask Monitoring Data 1982-83
Island L., Sk.				189				
Snake L, Sk				4.2				
Cluff Creek, Sk.				22.6				
Boulder Cr. Sk.	June/82	-		119				(Amok 1982) Environ. Sask. Monitoring Data 1982-83
	Oct/82	-		1.2				
Cluff L., Sk.	June/82	-		4.7				
	Oct/82	-		2.4				
Snake L., Sk	June/82	-		14.8				
	Oct/82	-		9.5				
Island L., Sk.	March/82			17.5				
	June/82			38.9				
	Oct/82			2.4				
ELLIOT L. AREA ONT.								
Long L. Overflow	1966-67				-	ug/L	262	Ontario Water Resources Commission 1972
	1967-68				-		392	
	1968-69				-		31	
Buckles Creek	1966-67				-		15	
	1967-68				-		43	
	1968-69				-		291	
Rochester Cr.	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
Strike Lake	1966-69				-		200	
Creek from Bud L.	1966-67				-		26	
	1967-68				-		28	
	1968-69				-		32	
Creek from Pronto Tailings Area	1966-67				-		27	
	1967-68				-		30	
	1968-69				-		28	
Crotch L.	1966-67				-		24	
	1967-68				-		16	
	1968-69				-		21	
BANCROFT L. AREA, ONT.								
Bentley Creek	1966-67				-		23	
	1967-68				-		92	
	1968-69				-		80	
Deer Creek	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Farrel Creek	1966-67				-	ug/L	<10	Ontario Water Resources Commission 1972 (cont'd)
	1967-68				-		<10	
	1968-69				-		<10	
QUIRKE LAKE BASIN								
Serpent R. between	1966-67				-		26,12	
Bud L and Stollery L	1967-68				-		28,24	
	1968-69				-		32,11	
Serpent R. just upstream	1966-67				-		<10	
of Quirke L.	1967-68				-		15	
	1968-69				-		15	
Quirke L.	1966-67				-		22	
	1967-68				-		22	
	1968-69				-		21	
Rochester Creek	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
Whiskey Lake	1966-67				-		11	
	1967-68				-		11	
	1968-69				-		14	
Upstream of Long L	1966-67				-		262	
	1967-68				-		392	
	1968-69				-		31	
West of Hwy #108 and	1966-67				-		<10	
south of Bud L.	1967-68				-		<10	
	1968-69				-		<10	
PECORS LAKE BASIN								
-between Crotch & McCabe	1966-67				-		24	
	1967-68				-		16	
	1968-69				-		21	
-McCabe L.	1966-67				-		11	
	1967-68				-		<10	
	1968-69				-		16	
-just n. of Half Moon	1966-67				-		623	
Lake	1967-68				-		1050	
	1968-69				-		843	
May Lake	1966-67				-		19	
	1967-68				-		33	
	1968-69				-		26	
-between Hough & Pecors L	1966-67				-		16	
	1967-68				-		<10	
	1968-69				-		19	
Pecors Lake	1966-67				-		<10,11	
	1967-68				-		<10,10	
	1968-69				-		<10,13	
ELLIOT LAKE BASIN								
Esten Lake	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Elliot Lake	1966-67				-	ug/L	10,13	Ontario Water Resources Commission 1972, cont'd
	1967-68				-		<10,12	
	1968-69				-		<10,17	
Between N. Nordic L and Nordic L.	1966-67				-		15	
	1967-68				-		43	
	1968-69				-		291	
Nordic L.	1966-67				-		28	
	1967-68				-		26	
	1968-69				-		170	
Depot L.	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
LOWER SERPENT RIVER BASIN								
Grassy Lake	1966-67				-		<10,<10,<10	
	1967-68				-		<10,<10,<10	
	1968-69				-		<10,<10,<10	
Camp Lake	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
McCarthy Lake	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
BANCROFT AREA								
Crowe River	1966-67				-		<10,<10,<10	
	1967-68				-		<10,<10,41.0	
	1968-69				-		<10,<10,32.0	
Eels Creek Hwy#26	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
Eels Lake	1966-67				-		<10	
	1967-68				-		10.0	
Downstream of Dyno L	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
Paudash Bay	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
Paudash Lake	1966-67				-		<10,<10	
	1967-68				-		<10,<10	
	1968-69				-		-,<10	
Mouth of Paudash Bay	1966-67				-		<10	
	1967-68				-		<10	
	1968-69				-		<10	
Bow Lake	1966-67				-		26,23,25	
	1967-68				-		107,92,143	
	1968-69				-		79,80,88	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
ELLIOT LAKE AREA								
Dunlop Lake Sta 18	1966-69	dredge	ug/g	4.7*				Ontario Water Resources Commission 1972, cont'd
		core-surf		4.*				
		-15"bel sur.		5.*				
Quirke Lake								
Sta. 25		dredge		39*				
				181*				
				82*				
				95*				
				113*				
				20*				
				14*				
				144*				
Whiskey Lake								
Sta. 29		dredge		25*,32*,12*				
		core-sur.		4*,3*				
		-4" bel sur		3*				
		-5" bel sur		3*				
		-10" bel sur		3*				
Pecors Lake								
Sta. 37		dredge		17*,15*,22*				
		core-sur.		10*,15*				
		-14"bel sur		3.0*				
		-21"bel sur		3.0*				
McCarthy Lake Sta 53		dredge		20*,9*				
McCabe lake, west end		dredge		175*				
Elliot Lake, Sta 48		dredge		189*,23*,17*				
				35*,26*				
		core-surface		4*,4*,4*				
		-1" bel sur		2.0*				
		-2" bel sur		2.5*				
		-8" bel sur		3*				
Nordic Lake		dredge		820*				
Depot Lake, Sta. 52		dredge		14*				
Camp Lake, Sta. 55		dredge		5*				
		core-surface		2.5*				
Serpent Harbour, Sta. 08		dredge		5*,2.5*				
		core-surface		5*,4*				
		-11"bel sur		2.5*				
		-29"bel sur		1.5*				
Buckles Creek		core-surface		57*				
		-1" bel sur		50*				
		-2" bel sur		66*				
Creek from Bud Lake		core-surface		100*				
		-1" bel sur		90*				
		-2" bel sur		85*				

*mean value

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Stollery Lake		dredge	ug/g	107*				Ontario Water Resources Commission 1972, cont'd
		core-surface		2.5*				
		-1" bel sur		2.0*				
		-2" bel sur		4.5*				
Horne Lake		core-surface		14*				
		-1" bel sur		3*				
		-2" bel sur		3*				
Bancroft Area	1966-69							
Bow Lake St. 71		dredge		230,300,220,29				
Paudash Lake, Sta. 75		dredge		11,130,38,29				
				37.17,25,1.5				
Eels Lake Sta. 80		dredge		17,10,12,9				
Near mouth of Farrel Cr.		-1" bel sur		32				
		-3" bel sur		35				
		-7" bel sur		16				
		-11" belsur		19				
WOLLASTON L. AREA, SK.	Aug/72	-	ppm		-	ug/L		Sawchyn 1973
Pow Bay - Stn J				156			2.04	
Hidden Bay				12,5,6,3			0.50	
Horseshoe Lake							4.32	
Rabbit L. Drainage Sta a							25.6	
b				65			11.6	
c							12.0	
d				62			9.2	
e				160			10.8	
f				56			3.66	
g				54			2.55	
Tailings Area Sta. 8-3							1.13	
8-5							3.54	
Parks Lake Sta. R				4				
Dawn Lake Area Sta. 1	1981	-	ug/g	1.0	-	ug/L	<0.5	Asamera 1982
2				2.1			<0.5	
3				2.3			<0.5	
4				3.6			<0.5	
5				3.2			<0.5	
6				1.9			<0.5	
7				0.9			0.9	
8				1.1			<0.5	
9				1.1			<0.5	
10				1.6			<0.5	
11				2.1			<0.5	
12				0.8			<0.5	
1	1982			3.7			<0.5	
3				2.6			<0.5	
5				1.7			<0.5	
6				2.5			<0.5	
7				1.8			<0.5	
8				1.0			<0.5	

*mean value

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Candy Lake Sk,	June/79				-	ug/L	<0.5	Canadian Occidental Petroleum 1980
Moffat Lake, Sk	May/79				-		<0.5	
McClean Lake, Sk							<0.5	
Mallen Lake, Sk.							<0.5	
Torwalt Lake, Sk.							<0.5	
Vulture Lake, Sk.							<0.5	
Kewen Lake, Sk							<0.5	
Collins Creek Sk.	June/79						<0.5	
	May/79						<0.5	
Wollaston L, Sk.	Aug/75						0.12	
Horseshoe L. Sk	Mar/75						1.4	
Douglas River, Sk.	Feb/76						0.26	
	Sept/79						0.14	
Candy L. Sk.	Sept/79	-	ug/g	1.5				
Moffat L. Sk				2.2				
McLean L. Sk				1.8,1.2				
Mallen L., Sk				2.3				
Torwalt L. Sk				1.7				
Vulture L, Sk				1.1				
Kewen Lake, Sk.	Sept/79	-	ug/g	1.6				
Lake #3, Ak.		-		0.88				
Key Lake South, Sk.	June/76				-	ug/L	<0.3	
	Mar/73						0.7	
	Aug/77						0.6	
	Oct/77						<0.5	
	Feb/78						<0.5	
Key Lake North, Sk.	Mar/77						<0.5	
	June/77						<0.5	
	Oct/77						<0.5	
	Aug/77						<0.5	
McDonald L, Sk.	Mar/77				surface		<0.5	
	June/77						<0.5	
	Aug/77						<0.5	
	Oct/77						0.9	
	Mar/77				bottom		<0.5	
	June/77						<0.5	
	Aug/77						0.8	
	Oct/77						0.5	
Zimmer Lake, Sk.	Mar/77				surface		5.2	
	June/77						1.1	
	Aug/77						1.0	
	Oct/77						2.5	
	Mar/77				bottom		2.2	
	June/77						1.8	
	Aug/77						1.2	
	Oct/77						1.8	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Outlet Creek Sk.	Apr/77				bottom	ug/L	<0.5	Canadian Occidental Petroleum 1980 cont'd
	June/77						<0.5	
	Aug/77						<0.5	
	Oct/77						<0.5	
	Feb/78						<0/5	
	Mar/78						<0.5	
	Aug/78						<0.5,<0.5	
Seahorse Lake, Sk.	June/76						2.7	
	Mar/77						1.6	
	June/77						3.9	
	Aug/77						1.3	
	Oct/77						2.5	
Lower Seashore Lake	June/76						3.4	
McDonald Creek, Sk	Apr/77						<0.5	
	June/77						<0.5	
	Aug/77						0.5	
	Oct/77						0.6	
	Feb/78						<0.5	
	Mar/78						<0.5	
	June/78						<0.5	
	July/78						<0.5	
	Aug/78						<0.5	
Wheeler River, Sk	Aug/77						<0.5,<0.5	
	Oct/77						3.7, 1.7	
	Feb/78						<0.5,<0.5	
	Feb/78						<0.5,<0.5	
	Apr/78						<0.5	
	June/78						<0.5,<0.5	
	June/78						<0.5	
	Aug/78						0.5,<0.5	
	Oct/78						<0.5,<0.5	
	Oct/78						<0.5,<0.5	
David Creek, Sk.	Oct/77						<0.5,<0.5	
	Feb/77						<0.5	
	Apr/78						1.0	
	June/78						<0.5,<0.5,<0.5	
	July/78						<0.5	
	Aug/78						<0.5	
	Oct/78						<0.5,<0.5	
Yak Creek, Sk.	Sept/77						<0.5	
	Oct/77						<0.5	
	Feb/78						<0.5	
	Mar/78						1.2	
	June/78						<0.5,<0.5	
	July/78						<0.5	
	Aug/78						3.8	
	Oct/78						<0.5	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Douglas Cr., Sk.	June/77					ug/L	0.5	Canadian Occidental Petroleum 1980, cont'd
	Aug/77						<0.5	
	Oct/77						<0.5	
Frank Lake Sk.	June/77						<0.5	
	Aug/77						<0.5	
	Oct/77						<0.5	
	Feb/78						0.7	
Hourglass L, Sk.	July/76						1.1	
	Apr/77						1.1	
Hourglass Cr. Sk	June/77						0.6	
	Aug/77						0.6	
	Oct/77						0.5	
Kathy Lake, Sk.	June/77						<0.5	
	Aug/77						<0.5	
	Oct/77						<0.5	
Lower Key Lake, Sk.	Sept/76						<0.3	
Murphy Lake, Sk.	Sept/76						0.3	
Lower Key outlet	Mar/77						<0.5	
Fred Lake, Sk.	Apr/77						<0.5	
Campbell Creek	Mar/77						2.2	
Hammer Creek	Mar/77						1.1	
Little McDonald Cr.	Mar/77						1.2	
Douglas L.	June/77						1.2	
Wrobel L.	June/77						<0.5	
Black L.	June/77						2.3	
Gerald L.	June/77						<0.5	
Lower Seahorse L.	June/77						3.4	
Karl Ernst L.	June/77						4.3	
Dieter L.	June/77						0.5	
Candy L.	June/79						<0.5	
	Mar/80						<0.5	
	June/80						<0.5	
	Aug/80						<0.5	
Moffat L.	Sept/79						<0.5	
	Mar/80						<0.5	
	June/80						<0.5	
	Aug/80						<0.5	
McClean L.	Sept/79						<0.5	
	Mar/80						<0.5	
	June/80						<0.5	
	Aug/80						<0.5	
Mallen L.	Sept/79						<0.5	
	Mar/80						<0.5	
	June/80						<0.5	
	Aug/80						<0.5	
Torwalt L.	Sept/79						<0.5	
	Mar/80						5.3	
	June/80						<0.5	
	Aug/80						<0.5	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Vulture L.	June/79					ug/L	<0.5	Canadian Occidental
	Mar/80						<0.5	
	June/80						<0.5	Petroleum 1980, cont'd
	Aug/80						<0.5	
Kewen L.	Sept/79						<0.5	
	Mar/80						1.8	
	June/80						<0.5,<0.5	
	Aug/80						<0.5,<0.5	
Collins Creek	Sept/79						<0.5,<0.5	
	Mar/80						5.4,<0.5	
	June/80						<0.5,<0.5	
	Aug/80						<0.5,<0.5	
Lake A	June/80						<0.5	
Lake B	June/80						<0.5	
Lake C	June/80						<0.5	
Lake D	June/80						<0.5	
Lake E	June/80						<0.5	
Camp Well	Mar/80						<0.5	
	June/80						<0.5	
	Aug/80						<0.5	
Collins Creek	1979	-	ug/g	0.7,1.2,1.1				
Collins Bay				1.0,4.7,3.0				
				7.8,38.1,2.6				
				3.3,3.5,4.4,				
				22.8,6.8,2.8				
				2.6,2.1,2.4				
				1.6,3.5,2.4				
				2.7,1.5,3.2				
				1.9,1.8,1.7,1.7				
				1.5,1.7,1.9,1.8				
				1.6,2.9,2.6,2.4				
				1.5,1.2,2.0				
				3.2,3.1,2.6				
Harrison L.	1979	-	ug/g	4.6,5.6,4.8,5.8				
Ivison Bay				1.9,1.5				
Upper Seahorse L.	July/79			520				
Little McDonald L.	July/77			169				
	Oct/78			160				
McDonald L.	July/77			62.7				
	Oct/78			23				
Key Lake	July/77			54.9,27.7				
	Sept/77			25.7,21.0				
	Oct/78			1.6				
Kathy L.	Sept/77			5.3				
Outlet Creek	Aug/77			5.3				
	Sept/78			0.17				
Wheeler River	Aug/77			10.2,6.2				
	Oct/78			0.06,0.15				
David Cr.	Sept/78			0.16				
Candy L.	Sept/80			2.3,2.3				
				2.3,2.7,2.2				

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
McClean lake	Sept/79		ug/g	1.2				Canadian Occidental Petroleum 1980, cont'd
	Sept/80			1.9,2.1,2.9 2.6,2.2,2.2 2.5,3.4,3.4, 3.4,2.5,2.3 2.3,15,1.8				
Moffat L.	Sept/79			2.2				
Mallen L.				2.3				
Torwalt L.				1.7				
Vulture L.				1.1				
Kewen L.				1.6				
Lake #3				0.88				
Wollaston Lake, Sk.								
Station 1	1979	0-2 cm	ug/g	2.5				Gulf Minerals Canada Ltd. 1980
		2-5		2.0				
		5-10		1.6				
		10-15		2.2				
		20-25		2.2				
Station 2		0-2		2.6				
		2-5		2.1				
		5-10		1.3				
		10-15		1.8				
		15-20		1.8				
		20-25		1.6				
Station 3		0-2		2.9				
		2-5		2.0				
		5-10		2.0				
		10-15		1.9				
		15-20		2.2				
		20-25		2.1				
Station 4		0-2		3.4				
		2-5		2.9				
		5-10		2.9				
		10-15		2.8				
		15-20		2.8				
		20-25		2.6				
Station 5		0-2		1.6				
		2-5		1.8				
		5-10		0.8				
		10-15		0.7				
		15-20		0.8				
		20-25		0.4				
Station 6		0-2		3.2				
		2-5		3.1				
		5-10		3.0				
		10-15		3.2				
		15-20		3.4				
		20-25		3.6				

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Station 7		0-2		0.8				Gulf Minerals Canada Ltd. 1980 cont'd
		2-5		1.3				
		5-10		1.1				
		10-15		1.2				
Station 8		0-2		0.8				
		2-5		1.3				
		5-10		4.9				
		10-15		14.0				
		15-20		14.2				
		20-25		16.8				
A-Zone		0-2		5.2				
		2-5		4.8				
		5-10		2.4				
		10-15		0.8				
		15-20		1.6				
		20-25		4.2				
B-Zone		0-2		271.0				
		2-5		128.0				
		5-10		10.0				
		10-15		1.9				
		15-20		2.0				
		20-25		2.2				
Wollaston L., Collins Bay								
Station 1	June/79				0 m	ug/L	0.16	
					1.5 m		0.60	
	July/79				0 m		0.16	
					1.5 m		0.25	
	Aug/79				0 m		0.10,0.21	
					1.5 m		0.08, 0.23	
	Sept/79				0 m		0.26,0.22	
					0 m		0.70,0.42	
Station 2	June/79				0 m		0.18	
					5.5 m		0.20	
	July/79				0 m		0.24	
					5.5 m		0.12	
	Aug/79				0 m		0.31	
					5.0 m		0.09	
					5.5 m		0.28	
	Sept/79				0 m		0.17,0.18	
					0 m		0.34,0.46	
Station 3	June/79				0 m		0.34	
					4.5 m		0.48	
	July/79				0 m		0.19	
	Aug/79				0 m		0.3,0.17	
					5 m		0.07, 0.11	
	Sept/79				0 m		0.16,0.13	
					0 m		0.70,1.58	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Sediment Sample Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Station 4	June/79				0 m	ug/L	0.32	Gulf Minerals Canada Ltd. 1980, cont'd
					8.5 m		0.36	
	July/79				0 m		0.13	
					7.5 m		0.11	
	Aug/79				0 m		0.18, 01.4	
					7.0 m		0.22,0.33	
	Sept/79				0 m		0.13,0.40	
					0 m		0.24, 0.46	
Station 5	June/79				0 m		0.30	
					2.0 m		0.26	
	July/79				0 m		0.06	
					2.0 m		0.12	
	Aug/79				0 m		0.14, 0.06	
					1.8 m		0.15	
					2.0 m		0.09	
	Sept/79				0 m		0.18,0.19	
					0 m		0.68, 1.12	
Station 6	June/79				0 m		0.34	
					10.5 m		0.24	
	July/79				0 m		0.09	
					10.0 m		0.13	
	Aug/79				0 m		0.22	
					8.0 m		0.28	
					10.5 m		0.07	
	Sept/79				0 m		0.07,0.03,	
					0 m		1.32,0.54	
Station 7	June/79				0 m		0.30	
					1.5 m		0.48	
	July/79				0 m		0.14	
					1.0 m		0.19	
	Aug/79				0 m		0.23,0.19	
					1.0 m		0.20,0.22	
	Sept/79				0 m		0.24,0.18	
					0 m		1.60,0.54	
Station 8	June/79				0 m		1.00	
					1.5 m		0.36	
	July/79				0 m		-	
					1.5 m		0.15	
	Aug/79				0 m		0.18, 0.17	
					1.5 m		0.48, 0.21	
	Sept/79				0 m		0.11,0.11	
Hendy Lake, Sk.	Sept/78					ug/L	<0.5	Canada Wide Mines 1981
	Feb/79						<0.5	
	July/79						<0.5	
	Aug/79						<0.5	
McMahon L., Sk	Sept/78						<0.5	
	Feb/79						<0.5	
	June/79						8.9	

Table 2.1 cont'd

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Smith Bay, Sk	Oct/78	profundal	ug/g(dry)	28	-	ug/L	<0.5	Canada Wide Mines 1981
	Feb/79						<0.5	
	June/79						<0.5	
	Aug/79						1.2	
Midwest lake, Sk	Oct/78						<0.5	
	Feb/79						<0.5	
	June/79						<0.5	
Lake W3	Sept/78						<0.5	
	Feb/79						<0.5	
	July/79						<0.5	
Nicholson Bay	Sept/78	profundal	ug/g(dry)	35			<0.5	
	Feb/79						<0.5	
	June/79						<0.5	
Too Small Lake	Sept/78						<0.5	
	Feb/79						<0.5	
	June/79						<0.5	
McClean L.	Oct/78						<0.5	
	Feb/79						<0.5	
	July/79						<0.5	
Collins Bay	Sept/78	profundal	ug/g (dry)	26			<0.5	
	Feb/79						<0.5	
	July/79						<0.5	
Nedvedicka River, Czech.	July/67	2cm	g/g (wet)	1.93		ug/L	2.625	Justyn and Stanek 1974
	June/67	2cm		18.25			4.500	
Lake Issyk-Kul USSR	1965	-	%	1.57×10^{-4}	-	%	3.3×10^{-6}	Kovalskiy and Vorotnitskaya 1965
				1.36×10^{-4}			3.10×10^{-6}	
				1.36×10^{-4}			1.70×10^{-6}	
				2.4×10^{-4}			3.68×10^{-6}	
				5.7×10^{-4}			2.30×10^{-6}	
				4.5×10^{-4}			4.32×10^{-6}	
				1.0×10^{-3}				
				8.7×10^{-4}				
				1.0×10^{-3}				
				1.58×10^{-3}				
				1.65×10^{-3}				
				1.8×10^{-3}				
				1.79×10^{-3}				
				2.2×10^{-3}				

TABLE 2.2

LEVELS OF URANIUM IN BENTHOS

Location	Sample Date	Identification of Benthos	Unit	Uranium Value	Reference
SERPENT RIVER BASIN, ONT.					Ontario Water Resources Commission 1972
- Serpent Harbour	1966-69	clam flesh	ug/g	20	
- McCarthy Lake	"	clam flesh		57	
- between Serpent Harbour & McCarthy Lake	"	crayfish		3	
- Elliot Lake	"	worms		160	
- between Quirke and Whiskey Lakes	"	crayfish		5,36	
UPPER CROWE EELS CREEK BASIN, ONT.					
- between Cordova & Bow Lakes	"	clam flesh		1	
- East of Paudash Lake	"	clam flesh		0.7	
- between Cordova & Bow Lakes	"	crayfish		1, 7	
- East of Paudash Lake	"	crayfish		0.3	
Fredette Creek, Sk.	1982	blackfly larvae	ug/g wet	0.39,0.16,0.28 0.12,0.19,0.25 0.18,0.42	Swanson 1984
		large odonata		0.17,0.19,0.33, 3.6,0.62,0.32	
		caddisfly larvae		2.3,2.8,4.4, 11,1.5	
Marie Lake, Sk.		caddisfly larvae		28,21,25,18 24,45	
Tailings Creek, Sk.		odonata blackfly larvae		3.7,5.7,6.6,5.9 1.4,1.0,1.4,1.8, 2.2,1.4,4.1,1.3, 4.9,1.7,0.8,2.5 2.0,0.9,1.6	
Tailings Cr., Sk, below 1st tailings lake	June/81	blackfly larvae	ug/g dry	20,8.4,49,17,9.6 13,90,10,18,13,12 24,12	Swanson 1982
			ug/g wet	2.583,1.675,9.959, 2.390,1.284,2.091 11.656,1.581,2.022, 1.507,1.856,4.160, 2.029	
Fredette Creek, Sk	"	blackfly larvae	ug/g dry	2.9,4.7,4.0,4.4, 4.4,8.3,6.4,6.8, 5.4,7.6,3.3,1.5, 5.8,4.4,2.6,4.4,3.2	

Table 2.2 cont'd

Location	Sample Date	Identification of Benthos	Unit	Uranium Value	Reference
Fredette Creek, Sk	June'81	blackfly larvae	ug/g wet	0.317,1.202,0.646, 0.637,0.661,1.211, 0.843,0.553,0.553 0.835,0.392,1.189 0.868,0.498,0.490, 0.896,0.550	Swanson 1982 cont'd
Fredette Creek, Sk	"	dragonfly nymphs	ug/g dry	12, 0.38	
			ug/g wet	2.303,0.105	
Tailings System at $BaCl_2$ plant	"	caddisfly larvae	ug/g dry	131,135,138	
			ug/g wet	21.674,23.122, 24.912	
Tailings System at Last point of control, Sk	"	dragonfly nymphs	ug/g dry	4.4	
			ug/g wet	1.281	
		backswimmer nymphs	ug/g dry	43	
			ug/g wet	14.186	
		dragonfly nymphs	ug/g dry	8.9	
			ug/g wet	2.419	
Mouth of Tailings Creek, Sk.	June'81	midge larvae	ug/g dry	56	
			ug/g wet	14.911	
Lake Issyk-Kul, USSR	1965	Gastropod -living on algae	% dry wt	$2.0x10^{-4}$	Kovalskiy and Vorotnitskaya 1965
				$1.56x10^{-4}$	
				$1.16 x10^{-4}$	
		-living on rocks		$6.2x10^{-5}$	
				$3.90x10^{-5}$	
		-skeleton		$2.25x10^{-4}$	
				$4.8x10^{-4}$	
				$1.55x10^{-4}$	
				$2.15x10^{-4}$	
		Tendipedidae larvae		$2.4x10^{-4}$	
		Gammaridae		$8.75x10^{-5}$	
				$7.8x10^{-5}$	
		Plecoptera larvae		$2.78x10^{-5}$	
				$1.40x10^{-5}$	
Yugoslavian stream (complete identification not available)	1981(?)	caddisflies	mg/kg dry wt	2.88	Stegnar and Kobal 1982
			wet wt	0.288	
		Gammarus fossarum	dry wt	0.06	
			wet wt	0.006	

TABLE 2.3

URANIUM DISTRIBUTION COEFFICIENTS (K_d) - SEDIMENT TO WATER

Location	Date Sampled	Sample Type	K_d Value (mL/g)	Reference
Beaverlodge L., Sk.	1979	wet	363	Swanson 1984
Millike L, Sk.			3200	
Fredette L, Sk.			2200	
Tailings System, Sk.			2.8, 0.3, 12, 223	
Fredette Creek, Sk.			700	

Table 2.4

BIOACCUMULATION FACTORS FOR URANIUM FROM WATER TO BENTHOS AND SEDIMENT TO BENTHOS

Location	Organism Identification	Uranium Bioaccumulation Factors Water-Benthos	Sediment-Benthos	Date Sampled	Reference
Okanogan Highlands, British Columbia	Pisidium(Mollusca)	3.06 $\frac{pCi/kg^{-1}}{pCi/L^{-1}}$	(.26 x wet weight)	(dry) -	Mahon 1982
Tailings System, Sk.	blackfly	0.60* $\frac{ug/g\ wet}{ug/mL\ wet}$	0.22* $\frac{ug/g\ wet}{ug/g\ wet}$	1982	Swanson 1984
	caddisfly	6.9*	0.30*		
	midge	0.88*	0.22*		
	dragonfly	11*	0.10*		
Fredette Creek, Sk.	blackfly	570*	0.27*		
	caddisfly	1000*	2.1*		
	dragonfly	870*	0.43*		
Tailings Cr., Sk. -below 1st tailings L.	blackfly	0.73 $\frac{Bq/g\ wet}{Bq/mL}$	0.23 $\frac{Bq/g}{Bq/g}$	June'81	Swanson 1982
-above $BaCl_2$ plant	caddisfly	5.4	0.59	"	
-at last pt. of control	dragonfly	0.31	0.04	"	
	backswimmer	3.5	0.48	"	
	damselfly	0.59	0.08	"	
-Tailings Cr. - mouth	midge	17	0.10	-	
Fredette Cr.	blackfly	317	0.32	June'81	
	dragonfly	522	0.52	"	
unavailable	invertebrates	60,100 $\frac{pCi/kg}{pCi/L}$		-	RECS 1978
Lake Issyk-Kul, USSR		1.56×10^{-4} & 1.16×10^{-4} & 6.2×10^{-5} & 2.0×10^{-4}	1.58×10^{-3} & 1.65×10^{-3} & 1.0×10^{-3} & 2.2×10^{-3}	1965	Kovalskiy & Vorotnitskaya 1965

* mean values

Note: 1 Bq = 27 pCi

3.0 THORIUM

3.1 Distribution in the Freshwater Environment

Thorium, atomic number 90, is a radioactive metal belonging to the actinide series, and a member of group IIIB in the periodic table of elements. It occurs in several isotopic forms, with half-lives ranging from 25.64 hours to 1.4×10^{10} years. It is ubiquitous in the earth's crust at an average concentration of about 12 to 15 ppm (Jonasson 1979, Luckey and Venugopal 1977). The most abundant form is Th-232 (half-life 1.4×10^{10} y) which is the parent nuclide of a long decay series terminating in stable Pb-208. The second long-lived isotope, Th-230, (half-life of 80,000 y) is a member of the U-238 decay chain and is generally present in minerals which contain uranium. Thorium-230 is also the immediate parent of Ra-226.

Thorium exhibits tetravalence (Th^{4+}) and its cationic salts, such as the nitrate and chloride, are water-soluble. With salts of more strongly basic metals thorium forms double (complex) salts which are similar in structure to potash alum. Highly charged but weakly basic Th^{++} has a strong tendency to complex formation with both inorganic anions and organic ligands. Aqueous solutions of highly acid salts such as $Th(NO_3)_4$ precipitate as hydroxides. However, when tetravalent thorium undergoes extensive hydrolysis above pH 3 it behaves more like a colloid than a true solute: this salt formation takes place in biologic fluids and tissues. As a consequence thorium is relatively insoluble at pH values greater than 3. If Th^{++} is complexed with citrate, hydrolytic salt formation and interaction of Th^{++} with other complexing agents is minimized (Luckey and Venugopal 1977).

Thorium exists in biologic fluids most commonly as a particulate

or colloidal polymer of hydrolytic thorium salts. Phosphate groups in the bone matrix have an affinity for thorium (Luckey and Venugopal 1977). This is consistent with the ICRP view that thorium is predominantly deposited on the surface of mineral bone (ICRP, 1979).

General ecological properties of thorium include: no nutrient analogues; principal exposure modes are through ingestion, inhalation and external gamma radiation; a very low degree of food chain transport; a successive trophic level concentration of less than 0.01; critical accumulation occurs in bone and the lung; very low to negligible assimilation; and a high (in the order of years) biological half-life (Whicker and Schultz 1982).

3.1.1 Thorium in Fresh Water

The concentration of thorium in natural surface waters is very low. Typical values of 0.00001 to 0.0001 ppm in freshwater and 0.000001 to 0.00005 ppm in seawater are cited (Jonasson 1979, Bowen 1966). Because it undergoes hydration, thorium is easily precipitated and adsorbed onto surfaces. Thus, only low concentrations are found in most natural waters (Koczy 1961). To illustrate this low abundance Table 3.1 gives concentrations of thorium in surface freshwaters in several different geographic areas.

3.1.2 Thorium in Freshwater Sediments

As recently as 1979, Jonasson stated that there was practically no information available on the thorium content of sediments. Very little new information has been added since, and sediment data associated with contemporaneous values for water, fish, plants and benthos are even scarcer.

It has been suggested that thorium is largely present in the coarser or heavy mineral fractions of stream sediments, retained in resistate minerals, especially those enriched in silica, titania, phosphates and aluminosilcates. Because thorium has a high affinity for surfaces, clay, such as kaolin and bentonite which have high surface area to volume ratios can be expected to scavenge thorium from the water column. Thus, in lake sediments, fine clays, organoclays and micaceous minerals are the most likely repositories of thorium (Jonasson 1979).

Th-228 and Th-232 levels in sediments from Great Bear Lake decreased significantly with increasing distance from an abandoned uranium mine and with increasing organic content of the substrate (Moore and Sutherland 1981).

Table 3.2 gives examples of thorium values in freshwater sediments from a few locations.

3.1.3 Thorium in Benthos

Data on the concentrations of thorium in freshwater benthic invertebrates are virtually nonexistent. Thompson et al (1972) cite a value of 0.02 ppm in an aquatic mollusc but whether this is for flesh only or whole animal is not specified. Clams from Lake Huron near Blind River were analysed for Th-227, Th-228, Th-230 and Th-232. Excluding Th-227, the mean concentration of the other three isotopes in flesh was 1.2 Bq/kg (wet) (SENES 1982). Predaceous dragonfly nymphs from a control pond at a nuclear generating station in New York State contained 0.40 ug/g thorium (dry weight) vs. 0.80 ug/g in nymphs from a flyash pond (Furr et al. 1979). Detritus feeders may be expected to ingest the thorium adsorbed to the surfaces of algal and macrophyte root particles, but since it has no biological function and no

essential chemical analogues it may not be incorporated into the body tissue of benthic invertebrates and may pass through the GI tract without significant accumulation. Thorium may be adsorbed to shells or chitinous exoskeletal parts of benthos. In the latter case this could lead to seasonal variation in the apparent thorium level, due to molting. The lack of useful information on the biokinetics of thorium in aquatic invertebrates and vertebrates is noted in a recent review paper by Trabalka and Garten (1983).

3.2 Aquatic Concentration Factors

3.2.1 Distribution Coefficients - Sediment to Water

Few contemporaneous data were found for thorium in water and sediments. Among these the values shown in Table 3.3 give positive results for sediment as "less than" values, which could be used only to set an upper limit on the distribution coefficient at a given site and time.

3.2.2 Bioaccumulation Factors - Water to Benthos

Thompson et al. (1972) calculated BF values for many elements in animals and plants in both fresh and salt waters, which have been widely cited. A value of 500 mL/g is given for thorium in unspecified freshwater invertebrates. Factors for three thorium isotopes, Th-228, Th-230, and Th-232 in the flesh of freshwater clams from the Blind River area of Lake Huron were found to lie in the range 400 to 700 mL/g (wet) (SENES 1982).

3.2.3 Bioaccumulation Factors - Sediment to Benthos

Differences in trophic level appear to determine the rate of sorption of elements from the environment into or onto the bodies

of benthic invertebrates. Wilhm (1970) demonstrated different rates of uptake of radioisotopes from contaminated detritus by detritivores and carnivorous macrobenthos. Detritivores reached peak concentrations of all radioactive isotopes by three days, while the carnivores, feeding on very small juvenile detrivores increased in activity for 14 days. This suggested that the transfer from substrate to animals was largely a surface-adsorption phenomenon. No comparable data could be found for the thorium series actinides in natural conditions.

3.3 Deficiencies in the Data Base

The deficiencies of the uranium data base listed in Section 2.3, also apply to the thorium data base.

It should be noted that environmental concentrations of thorium tend to be below the measurement capability of the currently practiced sampling and analytical techniques. Concentrations below the analytical threshold, expressed as "less than" values while perhaps useful for monitoring the performance of waste management facilities are of limited use in calculation of distribution coefficients or bioaccumulation factors.

Two questions need to be addressed. The first is "If it can't be measured, should we try?"; and the second is, "Is it biologically significant?" If both answers are yes, then the threshold of measurement must be lowered. While the solubility of thorium in natural settings is very low, it should be remembered that thorium isotopes have very low permissible levels of intake. Recent environmental pathways analysis suggest that intake of thorium could constitute a substantial fraction of total dose to human receptors (SENES 1983). Consequently, a better understanding of thorium pathways seems desirable.

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TABLE 3.1

TYPICAL THORIUM CONCENTRATIONS IN SURFACE FRESHWATER

Geographic Area	Water Source	Th. Content (µg/L) Min.	Max.	Weighted Mean	Average	Isotope	Ref.
Japan	10 Rivers	.0087	.048	.027		Th-tot	Miyake et al 1964
Brazil	Amazon R.				0.096	Th-232	Moore 1967
U.S.	Mississippi R.				0.044	Th-232	Moore 1967
Canada	Ottawa R. 7 Sta.	0.0008	0.002 ± 12%			Th-tot	Merritt 1975
Canada N. Sask.	McClean Lk. Area, 116 samples	n.d.	6.9		0.2	Th-tot	Canadian Occidenta. 1980

TABLE 3.2

THORIUM CONCENTRATIONS IN FRESHWATER SEDIMENTS

Geographic Location	Date	Sample Source	No. of Samples	Th Content (µg/g) Min.	Max.	Median	Isotope	Ref.
N.E. Saskatchewan	26/9/80	McClean Lk.	15	2.2	11		Th-tot	Canadian Occidental 1980
N.E. Saskatchewan	18/9/80	Candy Lk.	5	5.6	14		Th-tot	Canadian Occidental 1980
N. Saskatchewan	77-79	McClean Lk. Area	18	0.54 (Bq/g [dry wt basis])	13	6.0	Th-tot	Canadian Occidental 1980
N. Saskatchewan	77 & 78	Key Lk. Area	4	3.6	13		Th-230	KLMC 1982
N. Saskatchewan	82	Key Lk. Area	4	<0.01	0.02		Th-230	KLMC 1982

TABLE 3.3

DISTRIBUTION OF Th-230 IN WATER AND SEDIMENT

Location (Saskatchewan)	Date Sampled	Sample Type		Sediment		Water		Reference
		Sediment	Water	Unit	Value	Unit	Value	
Water Body								
McDonald Creek	18 June 82	x		Bq/g dry wt.	<0.01	mg/L	0.01	KLMC 82
	24 June 82		x			mg/L	0.01	KLMC 82
David Creek	19 June 82		x			mg/L	0.06	KLMC 82
	18 June 82	x		Bq/g dry wt.	<0.02			KLMC 82
Delta Lk.	14 June 82		x			mg/L	<0.01	KLMC 82
	14 June 82	x		Bq/g dry wt.	<0.01			KLMC 82
Russell Lk.	4 June 82		x			mg/L	<0.01	KLMC 82
	4 June 82	x		Bq/g dry wt.	<0.01			KLMC 82

4.0 RADIUM

4.1 Distribution in the Freshwater Environment

Radium belongs to group IIA in the periodic table, the alkaline earth elements. It has chemical properties similar to those of barium, has one oxidation state (+2) in solution, is highly basic and not easily complexed (Sheppard 1980). All of the isotopes of radium are radioactive, with half-lives ranging from 10^{-3} s to 1620 y (UNSCEAR 1977). From the point of view of environmental pathways and human exposure, only Ra-226 and Ra-228 (which gives rise to Ra-224) are of significance. Ra-226 has the longest half-life and is a daughter of uranium. It is the isotope most frequently studied with respect to food-chain transfer and effects near uranium mines.

Ra-226 is relatively insoluble with environmental levels typically reported in the ng/L range. Upon entering the water column, it quickly moves to sediments through adsorption or co-precipitation with barium or calcium (Sheppard 1980, Dyck 1974, Emerson and Hesslein 1973). The rapidity of removal to sediments was illustrated in an experiment with artificially introduced Ra-226 in a small lake; one month after addition approximately 90 percent of the Ra-226 was taken up on the bottom in the littoral zone (Emerson and Hesslein 1973). The proportion of Ra-226 going to sediments is controlled by the nature of the sediments, the chemistry of the water, and the biological community of the water body. Follow-up studies of four small Canadian Shield lakes where a single addition of Ra-226 was made showed that only 3 to 10 percent remained in the water column (Hesslein and Slavicek 1984). At Quirke Lake, Ontario, however, such dramatic reductions in radium levels were not observed (SENES and Golders

1981).

Removal of Ra-226 to sediments is controlled by adsorption more than co-precipitation in most cases (Morin et al 1981). The three major parameters controlling adsorption onto sediments are particle size, organic content whether or not it is part of living organisms and manganese or iron content.

Adsorption increases with decreasing particle size, and is greatest at sizes less than 100 um (Sheppard 1980, Dave et al 1981). This is because of greater surface area available with smaller grain size. Adsorption is greatest with fine clay mineral sediments (Dyck 1974, Sheppard 1980). The mechanism of adsorption is primarily cation exchange.

Adsorption is usually greater in sediments with high organic content (Dyck 1974, Titayeva et al 1978). The rapid removal of artificially added Ra-226 in small Canadian Shield lakes was due to adsorption onto periphytic algae or detrital material covering rocks in the littoral zone (Emerson and Hesslein 1973). Accumulation by live algae is primarily by adsorption onto cell surfaces; actual uptake is relatively uncommon, although some species of green algae can absorb Ra-226 (Havlik 1971, Havlik and Hanusova 1979). Uptake by dead cells (detritus) depends on the structure of the organic matter (Havlik 1971). In some cases, perhaps because of the nature of the organic material, uptake of Ra-226 in sediments is more dependent on other parameters, such as Ra-226 and calcium concentrations in the water, manganese concentration in sediments and actual uptake by benthic organisms, than on total organic content (Justyn and Stanek 1974, Dyck 1974).

Hydrous oxides of iron and manganese have long been known to adsorb trace elements from solution. Manganese oxides have very

high affinity for radium (Moore and Reid 1973). Therefore, in many cases, manganese oxides can account for much of the Ra-226 adsorbed onto sediments, particularly in the absence of organic material. Although iron oxides have less affinity for Ra-226, the much greater overall abundance of iron in most sediments may even out the effectiveness of the two elements (Dyck 1974).

Once deposited onto sediments, Ra-226 can be re-distributed by physical, chemical and biological phenomena. High flow periods in streams can scour organic material off the bottom and move finer sediments farther downstream until they are re-deposited in pool areas or at the mouths. Spring and fall turnover in lakes can transport littoral sediment material to profundal zones. Movement of Ra-226 from littoral to profundal areas was observed in the artificially-injected lakes studied by Emerson and Hesslein (1973). Sorption-desorption phenomena can also result in Ra-226 redistribution in sediments. For example, in anoxic waters in the hypolimnion of stratified lakes, manganese is reduced, releasing Ra-226 back into solution. When turnover occurs, the Ra-226 is re-adsorbed and redistributed (Hesslein and Slavicek 1984). Desorption from sediments is also related to the relative concentration of Ra-226 in water and sediment. Desorption increases as relative water concentration decreases via diffusion from sediment porewater (Canada Wide Mines 1981, Hesslein 1980). Cycling of Ra-226 through food chains also results in redistribution, as does the burrowing activity of sediment-dwelling invertebrates.

The general ecological properties of Ra-226 include: a chemical analogue of calcium; primary exposure routes are via ingestion, absorption or external gamma irradiation; a moderate degree of food chain transport; a successive trophic level concentration of less than 1.0; critical accumulation in bone; a moderate degree of assimilation; and a long (in the order of years) biological

half-life (Whicker and Schultz 1982).

One of the most important ecological properties governing the distribution of Ra-226 in ecosystems is its similarity to calcium, an essential nutrient for many biota. Because Ra-226 is an analogue of calcium, it follows the same biological pathways as calcium, but is favoured or discriminated against to a greater or lesser extent in different processes and organisms (Hesslein and Slavicek 1984). Studies of Ra-226 uptake relative to calcium uptake can aid predictions of Ra-226 concentrations along critical pathways. This approach is described in detail in Section 4.2.

Because Ra-226 is an analogue of calcium, it is primarily deposited in hard tissues such as bone or exoskeleton (thus the term "bone-seeking"). Bone-seeking elements are generally absorbed to a smaller extent than those that concentrate in soft tissue, but are retained more tenaciously (Whicker and Schultz 1982). Because they are deposited in relatively undigestible tissues (metabolic sinks), their mobility in food chains is only moderate (Whicker and Schultz 1982, Reichle et al 1970).

Uptake of Ra-226 in aquatic systems can be via absorption through integument or gills, or via food. The relative contribution from each source depends upon the physiology of the organism, its habitat and food preferences and the bioavailability of Ra-226 in water, sediment and food items. Knowledge of primary sources is essential for adequate modelling of critical pathways; available data and further work required will be reviewed in 4.2 and 4.3.

4.1.1 Ra-226 in Fresh Water

Ra-226 concentrations in water in unaffected areas are generally very low (Table 4.1). This reflects the geochemical properties

of Ra-226, discussed above, notably, its low solubility and propensity for adsorption or coprecipitation. Increased Ra-226 levels occur in lakes and streams receiving uranium mine, mill and waste management area effluents or drainage. Such effects can be seen in the Wollaston Lake area, Beaverlodge area and Cluff Lake area in Saskatchewan and the Elliot Lake and Bancroft areas in Ontario (Table 4.1).

Data on Ra-226 in water should be correlated with other water quality parameters that affect Ra-226 concentration and uptake in food chains. These parameters include pH, suspended solids, total dissolved solids, temperature, calcium, barium, bicarbonate and chloride concentrations. Generally, Ra-226 uptake from water is highest in soft-water lakes with low TDS (Whicker and Schultz 1982). Temperature affects the physical state of water and the metabolism of organisms in the water; therefore, it may have a profound effect on the behaviour of Ra-226 (Whicker and Schultz 1982).

Seasonal variations may greatly affect Ra-226 concentrations in natural waters. Bottom-water samples collected during summer stratification, for example, may have elevated Ra-226 levels compared to surface waters or to well-mixed water during spring and fall due to desorption of Ra-226 from the sediments under anoxic conditions.

Annual variations should also be monitored, both in unaffected and contaminated areas. Annual climatic phenomena, for example, may lead to pulses in Ra-226 levels which, in turn, result in increased food chain uptake.

4.1.2 Radium-226 in Freshwater Sediments

Sediment Ra-226 data are not as plentiful as those for water.

This is unfortunate, since sediments are the principal source of radionuclides in aquatic ecosystems and are also more variable. Sediments can contain several times the radium concentration of water, even in unaffected areas (Table 4.1).

Important parameters to include with sediment data are organic content, texture and manganese/iron content. This information aids in the interpretation of sediment Ra-226 levels (see foregoing discussion).

Lake morphometry may also be a factor affecting Ra-226 sediment levels. Hesslein and Slavicek (1984) found a linear correlation between mean depth and the fraction of Ra-226 in the water column. Summer and winter stratification will also affect sediment, water levels and Ra-226 dispersion within a lake. Sedimentation rate will affect the amount of Ra-226 in the upper (available to biota) sediment layers. The flushing rate will also affect relative Ra-226 concentrations.

4.1.3 Radium-226 in Benthos

Data on Ra-226 in benthic fauna or flora are scarce. Available data are summarized in Table 4.2. Variability is high, even within sample locations. Ra-226 levels in benthos can vary with several factors. The life stage of the organism can be very important; an insect larva immediately after moulting may have a much lower Ra-226 burden due to loss of previously accumulated Ra in the discarded exoskeleton. Food habits and habitat preference are directly related to radium uptake. As was noted for uranium, detritivores generally have higher levels than carnivores. Longevity will also affect total radium burden. For example, a fresh water clam will have a longer time to accumulate Ra-226 than a dipteran larva, which may inhabit an area for only a few weeks.

Mobility of benthic organisms is also a factor that has to be considered. Amphipods, for example, are often considered to be part of the benthos, yet are relatively mobile compared with sedentary fingernail clams. More mobile species may encounter greater range of Ra-226 levels, leading to greater variation in uptake.

4.2 Aquatic Concentration Factors

4.2.1 Distribution Coefficients - Sediment to Water

Radium-226 is primarily adsorbed to sediments by cation exchange. Distribution coefficients (K_d's) for radium reflect the cation exchange capacity of sediments, which in turn depends upon the physical and chemical nature of the soil particles and of the liquid phase. Generally, clay mineral and organic particles of colloidal size represent the major adsorptive component of sediments (Whicker and Schultz 1982). The surfaces of these particles are usually negatively charged and attract cations from solution. Cations may also replace one another on colloid surfaces, and the replacement power varies with the cation. Radium-226 has a relatively high replacement power, second only to mercury and strontium, among the more common ions (Whicker and Schultz 1982).

The use of one radium K_d value for an entire water body can be very misleading, because of the variable affinity of Ra for different sediment types. In general, K_d's are not useful in predicting the equilibrium or steady state concentration of Ra-226 in the water, unless detailed data are available on sediment types and amounts within the system (Benes 1982). It has been suggested that the mean depth of a lake relates better to the proportion of Ra-226 in the water column; the deeper the lake,

in the water (Hesslein and Slavicek 1984).

The K_d's presented in Table 4.3 show the overall tendency of Ra-226 to concentrate in the sediments; all of the K_d's are much greater than one. Generally, the K_d's are fairly consistent (within an order of magnitude) within regions, eg. Collins Creek watershed. However, considerable variability is evident in the Beaverlodge area, especially in the systems impacted by uranium mill tailings - Beaverlodge Lake and the Tailings Creek system. In the Tailings Creek system, there is a definite correlation between particle size and K_d; the coarser materials upstream do not contain as much Ra-226. In Beaverlodge Lake the overall K_d is much higher than in two nearby uncontaminated lakes despite fairly similar sediment types in the three lakes. Since Beaverlodge Lake is the deepest of the three study lakes, it does not appear to follow the trend found by Hesslein and Slavicek (1984), where deeper lakes have a higher relative Ra-226 concentration in the water column. Perhaps sediment-water interactions change somewhat as Ra-226 levels increase.

4.2.2 Bioaccumulation Factors - Water to Benthos

A review of the scarce data on water-benthos bioaccumulation factors shows variation with site (Table 4.4). Generally, BF's within species are higher in uncontaminated areas than in contaminated sites. For example, blackfly, caddisfly and dragonfly BF's from uncontaminated Fredette Creek are higher than the BF's in the contaminated Tailings Creek system. This phenomenon illustrates the problem with assuming constant BF's for any given species, regardless of source medium concentration. In the case of Ra-226 uptake by benthic fauna, high uptake in uncontaminated areas may be due to low calcium levels in the water leading to a greater relative uptake of Ra-226. This is probably the case in the Tailings Creek vs Fredette Creek

example; calcium levels are higher in Tailings Creek.

Water-benthos bioaccumulation factors also show considerable variation among species (Table 4.4). Accumulation is greatest in omnivorous or detritivorous species such as midges and caddisflies. Filter-feeding organisms, which consume suspended particulate matter, frequently have high bioaccumulation factors, eg. fingernail clams (Pisidium). Species higher up the benthic food chain, such as the predatory dragonflies, have lower BF's. Therefore, in benthic invertebrates, food habits appear to be an important factor governing Ra-226 uptake.

Bioaccumulation factors vary with tissue. This has been shown for fish (Swanson 1982,1983) and would be expected to occur in benthic invertebrates. In vertebrates Ra-226 is a bone-seeker; in invertebrates it would be expected to collect in calcareous tissues such as shells. The sole example of Ra-226 determination in separate invertebrate tissues showed a pronounced accumulation in the growing edge of snail shells (Van der Borght 1963, Table 4.4).

In invertebrates without calcareous tissues, such as most insects, Ra-226 accumulation patterns are difficult to predict. In insects, calcium is an essential element important in the maintenance of ionic balance, in acting as a co-factor of some enzyme systems, and as an integral part of other enzyme systems (Chapman 1969). It (and Ra-226) may therefore be present throughout several tissues, particularly the haemolymph. It is likely that much of the Ra-226 measured in benthic fauna is not actually incorporated, but rather is adsorbed onto the cuticle or is simply passed through the gut without being assimilated.

Some authors have suggested that, in the case of Ra-226, the use of radium/calcium ratios is more informative than the use of

bioaccumulation factors (Hesslein and Slavicek 1984). These ratios or "discrimination factors" are expressed by

$$\frac{\text{Ra in sample}}{\text{Ca in sample}} \div \frac{\text{Ra in water}}{\text{Ca in water}}.$$

The use of discrimination factors permits evaluation of the selection for and against radium as compared to calcium, which can vary greatly with species. For example, macrophytes show a discrimination in favor of Ra-226 (the ratio is >1), while certain teleost fish can show a strong discrimination against radium (ratios of <0.05) (Hesslein and Slavicek 1984). The mode of uptake also affects the degree of discrimination. In fish, discrimination against radium is greater in gill exchange than in ingestion; therefore, bottom-feeding fish tend to accumulate more radium than pelagic predatory fish (Swanson 1983, Hesslin and Slavicek 1984). It can be seen that, in the case of radium, more information about the mode of uptake and expected degree of food chain transfer may be available through the use of discrimination factors than through use of the highly site, species and tissue-specific bioaccumulation factors.

4.2.3 Bioaccumulation Factors - Sediment to Benthos

Because most of the Ra-226 in an aquatic system ends up in the sediment, sediment-benthos BF's are more meaningful than water-benthos BF's. Unfortunately, there are very few data available on sediment-benthos transfer (Table 4.4).

Existing data show that sediment-benthos BF's are low (≤ 2.0). This indicates an inefficient transfer from sediments to invertebrates. This has also been found for the transfer of plutonium from sediments to midge larvae (Trabalka and Frank 1978) and to crayfish (Delaney et al 1979).

Such low BF values imply that Ra-226 levels found in invertebrates may be due to passive modes of uptake (such as particles with adsorbed Ra-226 adhering to integument), rather than active processes linked to uptake of essential nutrients.

Sediment-benthos BF's vary with species in a manner similar to that shown by water-benthos BF's, ie. bottom feeders and filter-feeders have higher BF's than predators. This is to be expected, particularly if the main mode of uptake is ingestion.

Sediment-based BF's also varied with site. Again, BF's from uncontaminated areas were higher than from contaminated sites. This implies that calcium and Ra-226 uptake from sediments are linked in the same way they are in water; lower calcium levels mean higher Ra-226 intake. This linkage would operate in both possible modes of uptake; ingestion or direct absorption from sediment pore water.

Until more data are available on both water-benthos and sediment-benthos BF's, the degree of variation with water quality, sediment type, food habits, habitat preferences and physiology cannot be adequately assessed.

4.3 Deficiencies in the Data Base

The deficiencies of the uranium data base cited in Section 2.3, apply also to the radium data base. In addition to these deficiences, it should be noted that the collection of calcium data in water, sediments and benthos is necessary for a complete understanding of relative radium uptake in foodchains.

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Table 4.1
A REVIEW OF RADIUM-226 LEVELS IN SEDIMENT AND WATER

Location	Date Sampled	Ra-226 Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Collins Creek Watershed, SK								
- Lake Cl	Aug./79	Littoral	pCi/g(dry)	1.8		pCi/L	0.5*	Canada Wide Mines 1981
- Too Small L.		"		3.1			0.8*	
- McClean L.		"		2.1			0.1*, 0.5*	
- Collins Bay		"		0.1			0.5*	
Waterbury L. Watershed, SK								
- Lake Wl	Aug./79	Littoral		0.1			0.7*	
- Shallow Lake Inlet		"		2.4			0.3*	
- Shallow Lake Outlet		"		2.3			0.6*	
- Nicholson Bay		"		1.4			0.1*, 0.7*	
Hatchet L. Watershed, SK								
- Henday L.	Aug./79	Littoral		13.0			0.8*	
- McMahon L.		"					0.2*, 0.5*	
- Midwest Lake		"					0.7*	
- Smith Bay		"					0.9*	
- Smith Bay	Oct./78	Profundal		0.9				
Collins Cr. Watershed, SK								
- Lake Cl	Aug./79	Profundal		<0.1				
- McClean L.		"		0.7				
- Collins Bay		"		2.9				
- Collins Bay	Sept./78	"		2.5				
Waterbury L. Watershed, SK								
- Lake Wl	Aug./79	Profundal		0.1				
- Shallow L.		"		0.1				
- Nicholson Bay		"		14.3				
- Nicholson Bay	Sept./78	"		7.8				
Too Small Lake, SK	Aug./79	depth not		3100			0.5	
Cl. Lake, SK		available		1800			0.5	
Henday L., SK		"		13000			0.5	
Shallow L. Inlet, SK		"		2300			0.7	
Shallow L. Outlet, SK		"		2300			0.7	
Lake Wl., SK		"		100			1.9	
McClean L. Inlet, SK		"		2100			0.5	
Wollaston L., Collins Bay		"		100			0.5	
Waterbury L , Nicholson Bay		"		1400			0.8	
WOLLASTON LAKE, SK	1979	Core Section pCi/g (dry)				pCi/L		Gulf Minerals Canada
Collins Bay Station 1		0-2 cm		0.56	0 m		<0.1	Ltd. 1980
					1.5 m		<0.60	
		2-5 cm		0.35	0 m		<0.1	
					1.5 m		<0.1	

*mean values
Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Ra-226 Value	Reference
Collins Bay Station 1 cont'd	1979	5-10 cm	pCi/g (dry)	0.24	0 m	pCi/L	<0.1	Gulf Minerals Canada Ltd 1980 cont'd
					1.5 m		<0.1	
		10-15 cm		0.22	0 m		<0.1	
					1.5 m		<0.1	
		15-20 cm		0.26	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		0.22	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 2		0-2 cm		0.24	0 m		<0.1	
					5.5 m		<0.1	
		2-5 cm		<0.10	0 m		<0.1	
					5.5 m		<0.1	
		5-10 cm		0.20	0 m		<0.1	
					5.5 m		<0.1	
		10-15 cm		<0.10	0 m		<0.1	
					5.5 m		-	
		15-20 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 3		0-2 cm		0.10	0 m		<0.1	
					4.5 m		<0.1	
		2-5 cm		0.10	0 m		<0.1	
					4.5 m		-	
		5-10 cm		<0.10	0 m		<0.1	
					5.0 m		<0.1	
		10-15 cm		0.10	0 m		<0.1	
					5.0 m		0.1	
		15-20 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		0.10	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 4		0-2 cm		0.21	0 m		<0.1	
					8.5 m		<0.1	
		2-5 cm		0.21	0 m		<0.1	
					7.5 m		<0.1	
		5-10 cm		<0.10	0 m		<0.1	
					7.0 m		<0.1	
		10-15 cm		0.11	0 m		<0.1	
					7.0 m		<0.1	
		15-20 cm		0.12	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 5		0-2 cm		<0.10	0 m		<0.1	
					2.0 m		<0.1	
		2-5 cm		<0.10	0 m		<0.1	
					2.0 m		<0.1	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Ra-226 Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Collins Bay, Station 5 cont'd	1979	5-10 cm	pCi/g (dry)	<0.10	0 m	pCi/L	<0.1	Gulf Mineral Canada Ltd. 1980, cont'd.
					1.8 m		<0.1	
		10-15 cm		0.10	0 m		<0.1	
					2.0 m		<0.1	
		15-20 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 6		0-2 cm		0.66	0 m		<0.1	
					10.5 m		<0.1	
		2-5 cm		0.10	0 m		<0.1	
					10.0 m		<0.1	
		5-10 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
		10-15 cm		<0.10	0 m		<0.1	
					0 m		<0.1	
		15-20 cm		0.15	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		0.13	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 7		0-2 cm		<0.10	0 m		<0.1	
					1.5 m		<0.1	
		2-5 cm		<0.10	0 m		<0.1	
					1.0 m		<0.1	
		5-10 cm		<0.10	0 m		<0.1	
					1.0 m		<0.1	
		10-15 cm		0.10	0 m		<0.1	
					0 m		<0.1	
Collins Bay, Station 8		0-2 cm		0.11	0 m		<0.1	
					1.5 m		<0.1	
		2-5 cm		0.06	0 m		<0.1	
					1.5 m		<0.1	
		5-10 cm		0.13	0 m		<0.1	
					1.5 m		<0.1	
		10-15 cm		0.13	0 m		<0.1	
					1.5 m		<0.1	
		15-20 cm		0.12	0 m		<0.1	
					0 m		<0.1	
		20-25 cm		0.18	0 m		<0.1	
					0 m		<0.1	
Collins Bay A-Zone		core						
		0-2 cm		0.50				
		2-5 cm		0.22				
		5-10 cm		0.18				
		10-15 cm		<0.10				
		15-20 cm		0.29				
		20-25 cm		0.21				
Colling Bay B-Zone		0-2 cm		7.4				
		2-5 cm		2.8				

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Collins Bay B-Zone cont'd	1979	5-10 cm	pCi/g (dry)	0.32				Gulf Minerals Canada Ltd. 1980, cont'd
		10-15 cm		<0.10				
		15-20 cm		<0.10				
		20-25 cm		0.10				
Collins Bay Sta. F1		littoral		0.10				
Sta. F2		"		0.10				
Sta. F3		"		0.15				
Sta. F4		"		0.23				
		"		<0.10				
Sta. F5		"		0.16				
Sta. F6		"		3.40				
Sta. F7		"		0.20				
		"		0.15				
Sta. F8		"		<0.10				
		"		0.20				
Sta. F9		"		0.55				
		"		0.46				
Sta. F10		"		0.10				
Sta. F11		"		0.25				
Sta. F12		"		0.68				
Sta. F13		"		0.21				
Sta. F14		"		<0.1				
Sta. F15		"		<0.1				
Sta. F16		"		0.36				
Sta. F17		"		<0.1				
Sta. F18		"		<0.1				
Sta. F19		"		<0.1				
Sta. F20		"		0.18				
Sta. F21		"		<0.10				
Sta. F22		"		<0.10				
Sta. 1		"		0.33				
		"		0.26				
		"		0.32				
Sta. 2		"		0.10				
		"		0.19				
		"		2.80				
Sta. 3		"		<0.10				
		"		0.11				
		"		0.12				
Sta. 4		"		0.35				
		"		0.14				
		"		0.16				
Sta. 5		"		0.10				
		"		0.11				
		"		<0.10				
Sta. 6		"		<0.10				
		"		<0.10				

Note: 1 Bq = 27 pCi

Location		Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Ra-226 Value	Reference
Collins Bay	Sta. 7	1979	littoral	pCi/g (dry)	0.33				Gulf Minerals Canada Ltd. 1980, cont'd
	Sta. 8				0.44				
					<0.10				
					0.16				
WOLLASTON LAKE, SK		1972		pCi/g(dry)			pCi/L		Sawchyn 1973
-Collins Bay	Stn. H							nd*	
-Evison Bay	Sta.49							nd	
-Pow Bay:	Sta. J				7.55			nd	
	Sta. 31							nd	
	Sta. 37							0.13	
	Sta. 38							nd	
-Otter Bay	Sta. 23							nd	
-Hidden Bay	Sta. 6							nd	
	Sta. 12				0.65			nd	
	Sta. M							nd	
	Sta. N				3.05			nd	
	Sta. O				1.74			nd	
	Sta. P				3.18			nd	
	Sta. W							nd	
Horseshoe L.	Sta. X							0.99	
Parks Lake	Sta. Y				0.58			nd	
Rabbit Lake Drainage:	Sta. A							0.27	
	Sta. B				2.65			0.16	
	Sta. C							0.13	
	Sta. D				4.09			0.10	
	Sta. E				3.86			nd	
	Sta. F				3.55			0.10	
	Sta. G				2.03			nd	
Transitional	Sta. 69							nd	
Long Range:	Sta. 93							nd	
	Sta. 94							nd	
Tailings Area:	Sta. 8-3							7.47	
	Sta. 8-5							3.34	
Dawn Lake SK		1981		Bq/g(dry)			Bq/L		Asamera Inc. 1982
	1				0.05			<0.005	
	2				0.03			<0.005	
	3				0.03			<0.005	
	4				0.04			<0.005	
	5				0.03			<0.005	
	6				0.08			<0.005	
	7				0.02			<0.005	
	8				0.02			<0.005	
	9				0.02			<0.005	
	10				0.02			<0.005	
	11				0.03			<0.005	

*nd - not detectable
Note: 1 Bq = 27 pCi

Location		Date Sampled	Sediment Sample Depth	Ra-226 Sediment Sample Unit	Sediment Sample Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Dawn Lake	12	1982		Bq/g(dry)	0.01		Bq/L	<0.005	Asamera Inc. 1982
cont'd	1				0.15			0.01	cont'd
	3				0.03			0.01	
	5				0.03			0.01	
	6				0.04			0.01	
	7				0.03			<0.005	
	8				0.01			0.01	
MCCLEAN LAKE AREA, SK				pCi/g			pCi/L		
Candy Lake		Sept. 79			1.2			0.5	Canadian Occidental
Moffat Lake		Sept. 79			0.9			0.2	Petroleum Ltd.
McClean Lake		Sept. 79			1.4			0.2	1980
McClean Lake, east		Sept. 79			0.9			-	
Mallen Lake		Sept. 79			2.4			0.2	
Torwolt Lake		Sept. 79			1.2			0.2	
Vulture Lake		Sept. 79			0.8			0.3	
Kewen Lake		July 79			-			0.1	
Kewen Lake		Sept. 79			2.5			<0.1	
Collins Crack - upstream		Sept. 79			-			0.2	
Collins Crack - downstream		Sept. 79			-			0.2	
Lake #3		Sept. 79			0.8			-	
Geikie River		Nov. 76						0.1	
(below junction of		Feb. 78						<0.1	
Wheeler River)		July 78						0.3	
		Aug. 78						<0.1	
		Oct. 78						<0.1	
		Jan. 79						<0.1	
		Feb. 79						<0.1	
		Aug. 79						<0.1	
Ross Channel		Aug. 75						nd*	
		Sept. 75						<0.25	
		Feb. 76						nd	
		June 76						nd	
		Aug. 76						0.24	
		Sept. 76						0.2	
		Feb. 77						0.31	
-at mouth of Umperville River		Mar. 77						1.8	
		July 77						<0.1	
Hidden Bay		Feb. 77						<0.1	
		March 77						0.3	
		July 77						<0.1	
		Feb. 78						0.1	
		March 79						0.7	
Douglas River		Sept. 75						<0.25	
		Feb. 76						0.31±.05	
		Feb. 77						0.23±.05	
Key Lake, South, Sask.		June 76						<0.1	
		March 77						<0.1	
		Aug. 77						<0.1	
		Oct. 77						0.4	
* nd - not detectable		Feb. 78						0.4	

Note: 1 Bq = 27 pCi

Ra-226

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Sediment Sample Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Key Lake, North	March 77					pCi/L	9.5	Canadian Occidental Petroleum Ltd. 1980, cont'd
	June 77						<0.1	
	Aug. 77						<0.1	
	Oct. 77						2.3	
Key Lake Region	1977		pCi/g	13			<0.1	
				9.7			<0.1	
				2.8			<0.1	
				2.1			1.9	
				2.1			<0.1	
				8.7			<0.1	
				2			<0.1	
				1.2			2.1	
				2.4			1.0	
				5.1			<0.1	
							2.4	
							2.5	
							0.2	
							1.1	
							<0.1	
							0.5	
							0.4	
							<0.1	
							3.2	
							<0.1	
							0.2	
							<0.1	
							<0.1	
							<0.1	
							0.2	
							<0.1	
							0.7	
							0.5	
							<0.1	
							<0.1	
							0.3	
							<0.1	
							0.32	
							<0.1	
							<0.1	
							<0.1	
							<0.1	
							0.66	
							<0.1	
							<0.1	
							0.3	
							0.3	
							0.4	
							0.2	
							<0.1	
							2.4	
							<0.1	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Ra-226 Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Referenc.
Key Lake Region cont'd	1977		pCi/g			pCi/L		Canadian Occidental Petroleum Ltd. 1980, cont'd
							<0.1	
	1978			25			0.4	
				2.6			4.2	
				932			<0.1	
				2.9			<0.1	
				0.4			0.2	
				1.1			0.3	
				1.2			0.7	
							<0.1	
							<0.1	
							<0.1	
							0.4	
							<0.1	
							0.1	
							0.2	
							<0.1	
							0.2	
							<0.1	
							0.5	
							<0.1	
							0.2	
							0.5	
							<0.1	
							0.2	
							<0.1	
							<0.1	
							0.1	
							0.1	
							2.3	
							<0.1	
							0.4	
							<0.1	
							0.1	
							4.8	
							0.7	
							<0.1	
							<0.1	
							0.9	
							0.1	
							0.1	
							0.9	
	1976						<0.1	
							0.2	
							<0.1	
							<0.1	
							<0.1	
							0.4	
							1.6	
	1979			45			<0.1	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Value	Reference
Collins Creek, SK	1979		pCi/g	0.1				Canadian Occidental Petroleum Ltd., 1980, cont'd
				0.1				
				<0.1				
Collins Bay, Sk.	1979			<0.15				
				0.23				
				<0.10				
				0.16				
				3.40				
				0.20				
				0.15				
				<0.10				
				0.20				
				0.55				
				0.46				
				0.10				
				0.25				
				0.68				
				0.21				
				<0.10				
				<0.10				
				0.36				
				<0.10				
				<0.10				
				<0.10				
				0.33				
				0.26				
				0.32				
				0.10				
				0.19				
				2.80				
				<0.10				
				0.11				
				0.12				
				0.35				
				0.14				
				0.16				
				<0.10				
				0.11				
				<0.10				
				<0.10				
				<0.10				
				0.34				
Harrison Lake, SK	1979			0.18				
				<0.10				
				0.33				
				0.44				
Ivison Bay, SK	1979			<0.10				
				0.16				

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Ra-226 Value	Reference
Candy Lake SK	1979		pCi/g	1.2		pCi/L	0.5	Canadian Occidental
Sask.	1980			2.8			0.5	Petroleum Ltd.
				2.7			0.1	1980, cont'd.
				2.4			0.1	
				2.4				
				2.3				
Moffat Lake, SK	1979			0.9			0.2	
	1980						<0.1	
							<0.1	
							<0.1	
McClean	1979			1.4,0.9			0.2	
Lake, SK	1980			1.1,1.4,1.9,			<0.1	
				1.9,1.9,1.9,			<0.1	
				1.5,1.8,1.8,			<0.1	
				1.6,1.5,2.2,				
				2.0,2.6,1.3				
Mallen Lake, SK	1979			2.4			0.2	
	1980			-			<0.1	
							<0.1	
							<0.1	
Torwalt	1979			1.2			0.2	
Lake, SK	1980			-			<0.1	
							<0.1	
							0.1	
Vulture	1979			0.8			0.3	
Lake,SK	1980						<0.1	
							<0.1	
							0.2	
Kewen Lake, SK	1979			2.5			<0.1	
	1980						0.1	
							<0.1	
							<0.1	
							0.1	
							0.1	
Collins	1979						0.2	
Creek, SK							0.2	
	1980						<0.1	
							<0.1	
							0.1	
							<0.1	
							<0.1	
							<0.1	
Lake #3,SK	1979			0.8				
Lake A,SK	1980						<0.1	
Lake B,Sk							<0.1	
Lake C,SK	1980						<0.1	
Lake D,SK							<0.1	
Lake E,SK							0.1	
Camp Well							0.3	
							1.3	
							3.3	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Unit	Ra-226 Value	Water Sample Depth	Unit	Value	Reference
Beaverlodge Lake, SK	June 1976		pCi/g(dry)			pCi/L		Ruggles and Rowley 1978
-B2				720			10.6	
-B5				880				
-B9				16			6.9	
-B12				102				
-B15							2.2,1.2	
-B1	Sept. 1976			483±13				
-B2				910±13	top		8.6	
					bottom		5.5	
-B3				57±2				
-B4				902±25				
-B5				703±20				
-B6				391±10				
-B7				43±2				
-B8				19±1				
-B9				89±2	top		1.1	
					bottom		1.8	
-B10				12±.7				
-B11				12±.7				
-B12				93±2				
-B13				10±.7				
-B14				2.3±.4				
Ace Creek, SK	June 1976			700			48,24	
	Sept. 1976			997±24			0.7,10.2, 7.1,2.8, 1.6,<0.9, 0.8	
Tailings Creek, Sk	June 1976			275			10.8,10.7, 11.0,10.0, 18.9	
	Sept. 1976			879±35			17.0,14.0, 11,11,4.7	
				145				
Geer Lake, SK	Sept. 1976			341±10				
				78				
	June 1976						176,90, 115,98	
Fookes Lake, SK	Sept. 1977			1900				
				2550				
Fulton Lake, SK	Sept. 1977			0.51				
Fredette Lake, SK	Sept. 1976			1.8			<0.1	
Geer Lake, SK	June 1976						12.0	
							7.7	
	Sept. 1976						12.0	
Meadows Dam	June 1976						8.2	
							9.0	
	Sept. 1976						13	

Note: 1 Bq = 27 pCi

Ra-226

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Sediment Sample Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Treated Mine Water	June 1976					pCi/L	7 2	Ruggles and Rowley
	Sept. 1976						7.6	1978, cont'd
							4.8	
							4.4	
Fay Mine Water	June 1976						390	
							210	
							190	
							150	
Marie Lake, Sk	June 1974						176.90	
	Sept. 1976						1'5.98	
Collins Creek, SK:	no date							Canada '.de
-Lake Cl.		profundal	pCi/g (dry)	<0.1				Mines 1981
		littoral		1.8				
-McClean Lake		profundal		0.7				
		littoral		2.1				
-Collins Bay		profundal		2.9				
		littoral		0.1				
Nicholson Creek, SK:								
-Lake Wl		profundal		<0.1				
		littoral		0.1				
-Shallow Lake Inlet		profundal		<0.1				
		littoral		2.4				
-Nicholson Bay		profundal		14.3				
		littoral		1.4				
Smith Creek, SK:								
-Hendry Lake		profundal		-				
		littoral		13.0				
-Smith Bay		profundal		0.9				
Rabbit Creek, SK	July 1978		pCi/g(dry)	48,39, 169,142, 103,4.1, 505,591, 851,1200, 869,924, 223,74,1200		pCi/L	5.3 0.1	Robinson et al 1983
Pow Bay, Sask.				2.2,1.2	top		<0.1	
					bottom		<0.1	
Parks Creek, Sask.					na*		<0.1	
Collins Creek, Sask.					"		<0.1	
Hidden Bay, SK	July 1978			3.2,0.9, 7.7,1.2, 5.4,1.8, 0.8	top bottom na		<0.1 <0.1 <0.1	

*na = not available
Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Ra-226 Value	Reference
Effluent Creek System (Rabbit Lake Operation)	July 1978		pCi/g (dry)	2.4,3.9, 4.6,1.5, 1.8,2.1, 1.9,0.8, 3.9,0.8, 1.4,2.6, 0.9,0.5		pCi/L	3.7 2.4 1.2 2.1 1.0 1.2 <0.1	Robinson et al 1983 cont'd
Nero Lake, SK	1978		pCi/g	168 168 16 8.2 13 23		pCi/L	62 51 [illegible]4.8 [illegible]4.8 56 45	Ruggles et al unpublished
-Station 5	June 1976			14,11,3.7				
-Station 5	Sept. 1976			26 32				
Lake Athabasca,Sk, Sta5	Sept. 76				surface bottom		0.1 200	
Langley Bay - narrows	Sept. 76				-		0.7	
"	June 76						7.1	
Sta 2	June 76						10.5	
"	Sept 76						0.8	
Gunnar Pit discharge	Sept 76						1.6	
L. Athabasca (St. Mary's channel)	Sept 76						0.2,0.1	
Beaverlodge L - Sta.9	June 76						2.1	
	Sept 76						1.1	
Animas River, Colorado								
Sta 1	1958					pCi/L	0.5,0.6	Anderson et al 1963
Sta 2							0.5,0.7	
Sta 3							10.5,15.5	
Sta 4							9.1,15.5	
Sta 5							0.1,0.7	
Sta 6							0.2,0.3	
							7.2,8.4	
							5.7	
							8.1,8.7	
							6.3,7.2	
							2.9,3.4, 2.7	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Unit	Ra-226 Value	Water Sample Depth	Unit	Value	Reference
Wollaston L. SK								
-downstream of Airport Rd.	Aug/81		Bq/g	9.0				(Gulf Minerals Canada Ltd., 1980) Environ. Sask. Monitoring Data 1982-93
-sedimentation dam	April/81			2.88				
	Aug/81			13				
Pow Bay	Aug/81			0.17				
Horseshoe L.	Apr/81			0.138				
	Aug/81			0.14				
Hidden Bay	Aug/81			0.16				
Parks L. at north end	Aug/81			0.04				
Inflow delta to Pow Bay	Aug/81			0.15				
CLUFF LAKE SK:								
- Boulder Creek	Nov/81			0.05				(Amok 1980) Environ. Sask. Monitoring Data 1982-83
- Smoke Lake	Nov/81			0.03				
Cluff L. near outlet	Nov/81			0.02				
	June/81			0.05				
Snake L	Nov/81			0.04				
	June/81			0.04				
Boulder Cr. at Cluff L	June/81			0.60				
Island L	June /81			0.01				
	Nov/81			0.15				
Boulder Cr. near mouth	Nov/81			0.90				
RABBIT L., SK:								
Sedimentation Pond	Aug/80	NA	pCi/g	977				(Gulf Minerals Canada Ltd. 1980) Environ. Sask. Monitoring Data 1982-83
		0-2 cm		480				
		2-4 cm		150				
		4-6 cm		39				
		608 cm		26				
		8-10 cm		21				
		10-12 cm		11				
		12-14 cm		12				
		14-16 cm		9.6				
		16-18 cm		4.5				
Pow Bay		0-2 cm		1.9				
		2-5 cm		1.7				
		5-10 cm		<0.5				
		10-15 cm		<0.5				
		15-20 cm		0.7				
Horseshoe L.	Aug/80	0-4 cm		2.4				
		4-6 cm		0.7				
		6-8 cm		0.8				
		8-10 cm		<0.5				
		10-12 cm		<0.5				
Hidden Bay		0-2 cm		1.1				
		2-5 cm		2.1				
		5-10 cm		0.6				

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Unit	Ra-226 Value	Water Sample Depth	Unit	Value	Reference
RABBIT L., SK:		Eckman Dredge						
Downstream of Airport Rd.	June/82	"	Bq/g	0.71				(Eldor Mines 1982)
Sedimentation Dam	June/82	"		15				Environ. Sask.
Pow Bay	July/82	"		0.04				Monitoring Data
Horseshoe L.	June/82	"		0.20				1982-83
Hidden Bay	July/81	"		0.089				
Parks L at north end	June/82			0.27				
Inflow delta to Pow Bay	July/82	"		6.9				
KEY LAKE, SK:		na	Bq/g(dry)					
McDonald Creek	June/83			0.05				(Key Lake 1982)
David Creek	June/83			0.09				Environ. Sask.
Delta Lake	June/83			<.005				Monitoring Data
Russell Lake	June/83			.04				1982-83
Little McDonald	July/77			.48				
	Oct/78			.93				
McDonald Lake	July/77			.36				
	Oct/78			.10				
Outlet Creek	Aug/77			.04				
	Sept/78			.11				
David Creek	Sept/78			.04				
CLUFF L. SK:								
Boulder Cr. near mouth	May/83		Bg/g	0.35				(Amok 1983)
Island L. near outlet				0.20				Environ. Sask.
Snake L. Near outlet				0.06				Monitoring Data
Cluff Cr. at outlet				0.06				1982-83
CLUFF L., SK:								
Boulder cr. near mouth	June/82		Bg/g	2.0				(Amok 1983)
	Oct/82			0.02				Environ. Sask.
Cluff L, near mouth	June 82			0.08				Monitoring Data
	Oct/82			0.02				1982-83
Snake L, near outlet	June/82			0.04				
	Oct/82			0.06				
Island L.	Mar/82			<0.005				
	June/82			0.16				
	Oct/82			0.02				
Elliot L, Ontario								
1	1977				na	pCi/L	137	Moffett and Tellier
2							110	1977
3							135	
4							140	
5							118	
6							127	
8							90	
14							60	
16							102	
7							13	
9							70	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Ra-226 Value	Reference
Elliot Lake cont'd	1977		Bq/g			pCi/L		Moffet and Tellier
10							100	1977 cont'd
11							30	
12							100	
13							17	
15							40	
17							130	
18							27	
19							13	
20							13	
Ottawa River, Ont.	1970				na	pCi/L	0.20	Havlik 1970
Upper Bass L							0.26	
Lower Bass L							0.18	
Maskinonge L.							0.18	
Perch L							0.11	
- inlets							0.27	
- outlets							0.24	
							0.37	
ELLIOT LAKE AREA, ONT:								
Buckles Cr.	1966-67					pCi/L	11*	Ontario Water Resources Commission 1972
	1967-68						6.6*	
	1968-69						6.3*	
Rochester Cr.	1966-67						3.4*	
	1967-68						2.9*	
	1968-69						3.8*	
Creek from Bud L.	1966-67						13*	
	1967-68						17*	
	1968-69						8*	
Creek from Pronto Tailings	1966-67						17*	
	1967-68						13*	
	1968-69						16*	
Crotch Lake	1966-67						147	
	1967-68						148	
	1968-69						128	
Strike Lake	N.D.						<2	
Bentley Creek	1966-67						5.2*	
	1967-68						5.3*	
	1968-69						6.5*	
Deer Creek	1966-67						3.9*	
	1967-68						2.5*	
	1968-69						4.5*	
Farrell Creek	1966-67						13*	
	1967-68						13*	
	1968-69						[illegible]*	

*dissolved Ra-226
Note: 1 Bq = 27 pCi

Location	Date Sampled	Ra-226 Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
QUIRKE L. BASIN:						pCi/L		Ontario Water Resources
Serpent River	1966-67						13,13,12	Commission 1972
	1967-68						17,13,12	cont'd
	1968-69						8,10,10	
Quirke L	1966-67						25	
	1967-68						21	
	1968-69						20	
Quirke L at Rochester Cr.	1966-67						3.1	
	1967-68						2.9	
	1968-69						3.8	
Whiskey L	1966-67						21	
	1967-68						21	
	1968-69						15	
Stollery L	1966-67						240	
	1967-68						320	
	1968-69						460	
Pecors L Basin							96,80,96	
McCabe L							34,30,27	
Upstream half moon L							44,34,36	
Hough L							31,23,23	
May L							60,50,44	
Channel between Crotch L & McCabe L.							147,148,128	
ELLIOT L. BASIN:								
Elliot L	1966-67						2.1	
	1967-68						1.8	
	1968-69						2.7	
Between Elliot & Horne L	1966-67						15	
	1967-68						15	
	1968-69						12	
Nordic L	1966-67						23	
	1967-68						12	
	1968-69						7.0	
Depot L	1966-67						2.2	
	1967-68						2 5	
	1968-69						2.2	
Esten L	1966-67						3.8	
	1967-68						3.2	
	1968-69						2.6	
LOWER SERPENT R. BASIN:								
McCarthy L	1966-67						15.8	
	1967-68						12.9	
	1968-69						12.6	
Grassy Cr.	1966-67						9.6,8.0,3.5	
	1967-68						8.1,7.0,6.2	
	1968-69						8.5,8.0,6.2	

Note: 1 Bq = 27 pCi

Ra-226

Location	Date Sampled	Sediment Sample Depth	Unit	Value	Water Sample Depth	Unit	Value	Reference
Camp L.	1966-67					pCi/L	12.3	Ontario Water
	1967-68						9.2	Resources Commission
	1968-69						11.8	1972 cont'd
ELLIOT L. AREA ONT:*								
Dunlop L	1966-69	Dredge	pCi/g	1.8				
		Core surface		0.8				
		Core-15" below surface		1.1				
Quirke L		dredge		10.4,21,12,23				
				37,9.2,7.6,40				
Whiskey L		dredge		16,13,8.7				
		core suface		2.5,6				
		core - 4" bel.sur.		1.7				
		- 5" " "		1.5				
		-10" " "		1.5				
Pecors Lake		dredge		16,18,22				
		core-14" bel.sur.		1.4				
		-21" bel.sur.		4				
McCarthy L		dredge		7,3.2				
McCabe L, west end		dredge		330				
Elliot Lake		dredge		35.4,8.5,8.8				
				15,8.0				
		core surface		11,15,1.7				
		core -1" bel.sur.		3				
		-2" bel.sur.		1.8				
		-8" bel.sur.		2				
Nordic L. (near inlet Buckle Cr.)		dredge		510				
		core surface		510				
		core -4" bel.sur.		510				
		-15" bel.sur.		510				
Nordic L (near centre)		core-7"bel.sur.		510				
		core-6"bel.sur.		510				
		center surface		510				
Depot L		dredge		5.5				
Camp L.		dredge		10.3				
		core surface		1.9				
Serpent Harbour		dredge		17.4,6.0				
		core surface		12,11				
		-11" bel.sur.		1.2				
		-24" bel.sur.		1				
Buckles Cr.		core surface		240				
		-1" bel.sur.		275				
		-2" bel.sur.		475				
Creek from Bud L.		core surface		400				
		-1" bel.sur.		320				
		-2" bel.sur.		340				

*all values are means
Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Unit	Ra-226 Value	Water Sample Depth	Unit	Value	Reference
Stollery L.		dredge	pCi/g	96.3				Ontario Water Resources Commission 1972, cont'd
		core surface		3.4				
		-1" bel.sur.		2.4				
		-2" bel.sur.		10.1				
Horne L.		core surface		4				
		-1" bel.sur.		2.4				
		-2" bel.sur.		2.3				
BANCROFT AREA, ONT:	1966-69							
Centre Lake		core-1"bel.sur.		2.5				
		core-9" bel.sur.		1.5				
Bow L.		dredge		110,290,73,39				
		core-1" bel.sur.		28				
		-2" bel.sur.		22				
		-3" bel.sur		2.5				
		-8" bel.sur.		3				
Near mouth Bentley Cr.		-1" bel.sur.		30				
		-4" bel.sur.		16				
		-8" bel.sur.		14				
Paudash L		dredge		86,280,8,34,4.3				
				21,50,9				
Inlet Bay		core-1" bel.sur.		58				
		-2" bel.sur.		4.5				
		-3" bel.sur.		2.5				
		-8" bel.sur.		2.5				
		-15" bel.sur.		5				
Eels Lake		dredge		5,23,7,9				
Near mouth Farrel Cr.		core-1" bel.sur.		25				
		-3" bel.sur.		62				
		-7" bel.sur		3.5				
		-11" bel.sur.		4				
Chandos Lake		dredge		1.5				
Uranium Complex, Bihar, India			pCi/g					Markose et al 1978
Tailings pond drain				210.0				
stream 1				268.5,55.1				
stream 2				21.2				
Riverbed-downstream				3.2				
Tailings Creek System, SK:	1982		Bq/g					Swanson 1984
-below Fookes Lake				3.0,0.50,0.20				
-Marie Lake				3.0,0.50,0.40				
-Meadows Lake				0.03,0.20,0.07				
Tailings Cr. mouth				1.7,1.4,2.0				

Note: 1 Bq = 27 pCi

Ra-226

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Sediment Sample Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Beaverlodge L, SK	1982		Bq/g					Swanson 1984 cont'd
Site 1				1.6,1.7,1.4				
Site 2				15,16,12				
Site 3				0.9,5,0.65,1.1				
Site 4				1.6,1.9,1.1				
Site 6				2.5,2.0,1.5				
Site 7				0.95,1.0,0.49				
Milliken L. SK	1982							
Site 1				0.02,0.03,0.02				
Site 2				0.03,0.03,0.14				
Site 3				0.08,0.13,0.15				
Site 4				0.02,0.02,0.03				
Fredette L, SK	1981							
Site 1				0.02,0.02,0.02				
Site 2				0.06,0.04,0.09				
Site 3				0.03,0.03,0.01				
Site 4				0.12,0.08,0.16				
Tailings Cr at Beaverlodge L	June/82					Bq/L	0.05	
Meadows							0.20	
Marie							1.0	
Tailings below Fookes							5.5	
Fredette R. at Fredette L.							0.18	
Beaverlodge Lake, SK:	Sept/81							Swanson 1982
Sta 1					11 m	Bq/L	0.06	
Sta 2					38.5 m		0.05	
Fredette Lake, SK:								
Sta 1							<0.005	
Sta 2							<0.005	
Milliken Lake, SK:								
Sta 1							<0.005	
Sta 2							<0.005	
Fredette Cr.	June/81		Bq/g(dry)	0.02,0.03,0.01				
				0.03,0.03,0.03				
Tailings Cr. below 1st Tailings	June/81			0.5,0.40,1.1				
Tailings System above $BaCl_2$ treatment				1.6,1.1,1.0				
Tailings system at last point of control				0.14,0.55,0.14				
ELLIOT L. AREA ONT:						pCi/L		R.E.C.S. 1978
Operating tailings								
Long Lake							70	
Quirke L							250	
Non-Operating Tailings								
Nordic							240	
Stanrock							110	

Note: 1 Bq = 27 pCi

Location	Date Sampled	Sediment Sample Depth	Sediment Sample Unit	Ra-226 Value	Water Sample Depth	Water Sample Unit	Water Sample Value	Reference
Jordan R. Utah	1961		pCi/g (dry)	3.5	-	pCi/g	0.0	Pendleton et al, 1964
	1960			1.4				
	1960			13.8				
	1960			4.7				
	1960			9.4				
	1961			13.4				
Langley Bay, Sta 1	July/78		pCi/g (dry)	1240,140,235				Ruggles, Robinson, and Zaidi (unpublished)
2				424,317				
3				4.0,100, 694				
				1300,347				
Lake Athabasca, SK 5				16				
6				8.1				
7				1.6,0.9				

Note: 1 Bq = 27 pCi

TABLE 4.2

LEVELS OF RADIUM-226 IN BENTHOS

Location	Sample Date	Identification of Benthos	Unit	Ra-226 Value	Reference
Fredette Creek SK	1982	Blackfly Larvae	Bq/g wet	0.02,<0.005,0.01 <0.005,0.01,0.01 0.01,0.02	Swanson 1984
		Large Odonata	"	0.01,0.01,<0.005, <0.005,0.09,0.01	
		Caddisfly Larvae	"	0.55,0.03,0.02, 0.01,0.04	
Marie L. SK	"	Caddisfly Larvae	"	0.01,0.45,0.95 1.2,0.55,1.0	
Meadows, SK	"	Odonata	"	<0.005,<0.005 <0.005, 0.02	
Tailings Creek, SK	"	Blackfly Larvae	"	0.35.0.45,0.45 0.40,0.30,0.45 0.35,0.75,1.0,0.80 0.70,0.70,0.55,0.60, 0.75	
Tailings Creek SK. (below first tailings lake)	June 81	Blackfly Larvae	Bq/g (dry)	1.7,2.5,4.5,4.0 5.0,3.5,5.5,3.5, 4.5,5.5,6.0,5.5,5.0	
			Bq/g (wet)	0.219,0.498,0.914 0.862,0.669,0.563 0.712,0.553,0.505 0.637,0.928,0.953 0.845	
Fredette Creek	"	Blackfly Larvae	Bq/g (dry)	0.02,0.02,0.07,0.06, 0.08,0.07,0.20,0.08, 0.11,0.05,0.08,0.13, 0.10,0.05,0.02,0.02, 0.02	
	June 1982	Blackfly Larvae	Bq/g (wet)	0.002,0.005,0.011, 0.008,0.013,0.010, 0.026,0.006,0.011, 0.005,0.009,0.010, 0.014,0.005,0.013, 0.004,0.003	Swanson 1982
		Dragonfly nymphs	Bq/g (dry)	0.01,0.04	
			Bq/g (wet)	0.001,0.011	

Table 4.2 cont'd

Location	Sample Date	Identification of Benthos	Unit	Ra-226 Value	Reference
Tailings Systems at BaCl2 plant *		Caddisfly larvae	Bq/g (dry)	8.0,7.5,5.0	Swanson 1982 cont'd
			Bq/g (wet)	1.323,1.284,0.902	
Tailings system at last point of control		Dragonfly nymphs	Bq/g (dry)	0.01	
			Bq/g (wet)	0.002	
		Backswimmer nymphs	Bq/g (dry)	0.10	
			Bq/g (wet)	0.032	
		Damselfly nymphs	Bq/g (dry)	1.1	
			Bq/g (wet)	0.299	
		Midge larvae	Bq/g (dry)	1.3	
			Bq/g (wet)	0.346	
SERPENT RIVER BASIN, ONT.	1966-69	Clam flesh	pCi/g (dry)	419	Ontario Water Resources Commission 1972
-McCarthy L				160	
-Serpent Harbour		Caddisfly Larvae		34	
		Midges		65	
Between Serpent Harbour & McCarthy R.		Caddisfly larvae		18	
		Crayfish		69	
Between McCarthy & Depot L		Midges		65	
Depot L.		Caddisfly larvae		7	
Between Esten & Elliot L.		Midges		25	
Elliot L.		fCaddisfly larvae		8	
		Midges		27	
Between Pecors & McCarthy L		Worms		25	
Pecors L.		Caddisfly larvae		7	
		Caddisfly larvae		12	
between Pecors & Whiskey L.		Midges		35	
		Caddisfly larvae		13	
East of Pecors Lake		Crayfish		26	
		Caddisfly larvae		5	
between Quirke & Whiskey L.		Crayfish		6	
		Caddisfly larvae		8,5	
		Crayfish		37,45	
Quirke L.		Midges		58	
		Caddisfly larvae		21	
between Quirke & Dunlop L		Midge		25	
Dunlop L.		Caddisfly larvae		20,7,11	
		Caddisfly larvae		1	
North of Dunlop L.		Crayfish		2	
		Midges		29	
North of Quirke L		Caddisfly larvae		4	
		Crayfish		1	
		Caddisfly larvae		1	

Note: 1 Bq = 27 pCi

Table 4.2 cont'd

Location	Sample Date	Identification of Benthos	Unit	Ra-226 Value	Reference
UPPER CROWE RIVER - EELS CREEK BASIN, ONTARIO	1966-69				Ontario Water Resources Commission 1972 cont'd
-Crowe L		Clam		3	
-Crowe R		Caddisfly larvae	pCi/g(dry)	17	
		Clam		105	
		Crayfish		0.9,17	
between Chandos L. & Bow L		Caddisfly larvae		33	
		Crayfish		60	
Bow Lake		Caddisfly larvae		80	
		Crayfish		280	
Eels Creek		Caddisfly larvae		5	
Eels L.		Crayfish		130	
		Caddisfly larvae		180	
East of Paudash L.		Crayfish		18	
		Clam		61	
Paudash L.		Midges		44	
between Paudash & Centre L.		Midges		150±75	
		Crayfish		190,73,5	
Animas R., Colorado	1958-59	Insects	pCi/g		Anderson et al 1963
Station 1				3.2,7,2.5	
3				1.4,1.9,3,5.7	
2				71	
4				160,230,200	
5				68,120,180	
6				17,33,12	
Serpent River Basin, Ont.	1966-69	Caddisfly	pCi/g (dry)	1-34	Ruggles and Rowley 1978
		Midge		29-65	
		Crayfish		1-69	
		Clams		160-419	
Crowe-Eel River Basin, Ont		Caddisfly		17-180	
		Midge		24-150	
		Crayfish		0.9-280	
		Clam		3-105	
COLLINS BAY, WOLLASTON L., SK	1979		pCi/g (dry)		
Station 1		Diptera		0.4±0.2	Gulf Minerals Canada Ltd. 1980
		Tircnoptera		4±2	
		Amphipoda		4±2	
		pelecupoda		1±1	
Station 2		Diptera		1±1	
		Trichoptera		2±2	
		Camphipoda		10±4	
Station 3		Diptora		2±2	
		pelecycopa		0.6±0.2	
		Amphipoda		0.6±0.2	

Note: 1 Bq = 27 pCi

Table 4.2 cont'd

Location	Sample Date	Identification of Benthos	Unit	Ra-226 Value	Reference
Station 4		Amphipoda		0.3±0.1	Gulf Minerals Canada Ltd. 1980 cont'd
Station 5		Amphipoda		0.5±0.2	
		Petecypoda		0.9±0.5	
Station 6		Amphipoda		2.4±0.5	
Station 7		Diptera		0.4±0.4	
		Pelecypoda		1±1	
		Amphipoda		7±4	
Station 8		Diptera		1±1	
		Polocypoda		1±1	
		Amphipoda		5±5	
Elliot L. area, Ont. -Dunlop L		Caddisfly larvae	pCi/g	1	
		Midge larva		29	
		Crayfish		2	
Other Stations		Caddisfly larva		1-34	
		Midge larvae		26-65	
		Crayfish		1-69	

Note: 1 Bq = 27 pCi

Table 4.3

RADIUM-226 DISTRIBUTION COEFFICIENTS (K_d) - SEDIMENT TO WATER

Location	Date Sampled	Sample Type	K_d Value (mL/g) littoral	K_d Value (mL/g) profundal	Reference
Collins Cr. Watershed, SK	1979	littoral/profundal	littoral	profundal	Canada Wide Mines
-Lake C1.		sediments	3600	-	1981
-Too Small L.			6200	-	
-McClean Lake			-	1800	
-Collins Bay			-	5400	
Beaverlodge L, SK	1982	Sediment	15833		Swanson 1984
Milliken L., SK			2000		
Fredette L. SK			1000		
Tailings Cr. System					
- below 1st lake			205		
- above $BaCl_2$ treatment			1207		
- below $BaCl_2$ treatment			3450		
- mouth of Creek			5400		
Fredette Creek			2000		
Uranium Complex, Bihur, India		Sediment			Markose et al 1978
-Sediments in tailings pond drains			2.9×10^3		
-Stream 1 @ 1.5 km			11.9×10^3		
@ 2.5 km			6.7×10^3		
-Stream 2 2.5 to 3 km			7.3×10^3		
-Riverbed downstream			5.4×10^3		
Collins Bay, Wollaston L. SK	1979	Sediment	171 (mL/g dry)		Gulf Minera.s Canada Limited 1980

TABLE 4.4

BIOACCUMULATION FACTORS FOR RADIUM-226 FROM WATER TO BENTHOS AND SEDIMENT TO BENTHOS

Location	Organism Identification	Ra-226 Bioaccumulation Factors Water-Benthos	Sediment-Benthos	Date Sampled	Reference
		(mL/g wet)			
Tailings Creek, SK					
- below 1st Tailings L.	Blackfly	219	1.14	June-July/81	Swanson 1982
- above BaCl2 plant	Caddisfly	5862	1.56	"	
- @ last point of control	Dragonfly	50	0.008	"	
	Backswimmer	833	0.13	"	
	Damselfly	7500	1.25	"	
Tailings Creek					
- mouth	Midge	9558	0.12	"	
Fredette Creek	Blackfly	455	0.45	"	
	Dragonfly	300	0.30	"	
		(L/kg wet)			
Animas R. Colorado	Invertebrates	500 - 1000	-	-	R.E.C.S. 1978
Elliot L. Basin		200 - 10,000	-	-	
		(mL/g wet)			
Tailings Creek System, SK	Blackflies	153	0.74	1982	Swanson 1982
	Caddisflies	1417	1.1		
	Dragonflies	41	0.01		
	Midge Larvae	7000	1.3		
Fredette Creek System, SK	Blackflies	450	0.90		
	Caddisflies	6500	13		
	Dragonflies	1000	2.0		
		(L/kg dry)			
Okanagan Highlands, BC	Pisidium (Mollusca)	3900			Mahon 1982
	Crustacea	250			
	Mollusca	250			
		(mL/g dry)			
Collins Bay, Wollaston L. SK	Benthos	1329		1979	Gulf Minerals June 1980
Oak Ridge, Tenn.	Detritivorous Invertebrates	0.5			Reichle et al 1970
Laboratory	Lymnaea stagnalis	edge of shell: 1,277± 375 shell without edge: 376 ± 100 Soft parts:108±18 Blood: 21±4		-	Van der borght 1963
Zirsovski mining area, Yugoslavia	invertebrates	650		-	Blaylock 1982
Jaduguda mining area, India	Invertebrates	1-2		-	Blaylock 1982

5.0 LEAD

5.1 Distribution in the Freshwater Environment

Lead is a heavy metal belonging to group IVA of the periodic table. It has several radioactive isotopes, of which lead-210 (half-life of 21 y) is the most plentiful. The main natural source of Pb-210 in the environment is the gaseous Rn-222, which escapes into the atmosphere from the earth's crust, and its daughter products which fall out with aerosol particles (Ladinskaya et al 1973). As a member of the uranium decay series, Pb-210 occurs in uraniferous geological formations. Nuclear weapons tests have contributed to elevated atmospheric Pb- 210 levels.

The concentration and availability of lead in freshwater is highly dependent on pH and alkalinity. In most natural waters it is probably complexed with organic ligands, giving soluble, colloidal and particulate compounds whose nature is not well known (Demayo et al 1980).

At pH values of 5 of 7 and in the presence of suspended clay particles, most metal ions including lead are precipitated and sorbed as hydroxide ions. At values of pH 6 to 10, the dominant species is calculated to be $Pb(OH)^{+}$. The presence of anions that can form salts of low solubility with lead, such as sulphate and phosphate also reduce the dissolved lead concentration. At pH values of less than 5, the formation of stable cationic species can prevent formation of the hydroxyl species. The formation of certain ligands may also inhibit adsorbtion to clay particles (Farrah and Pickering 1977, cited by Demayo et al 1980).

Between pH 6 and 8, the solubility of lead is a complex function

of pH and dissolved carbon dioxide concentration. At pH 6.5 and low alkalinity, the solubility approaches or exceeds 1.0 mg/L while above pH 8 in water containing CO_2 but no sulphur species, regardless of alkalinity, the calculated solubility is less than 0.01 mg/L (Hem and Durum 1973 cited by Demayo et al. 1980). Solubility is also very low in reducing systems down to pH 2 (Demayo et al. 1980).

Lead is not an essential element for the metabolism of plants or animals. It is an accumulative metabolic poison, exhibiting greatest toxicity in its soluble forms. The Canadian recommended maximum concentration of total lead in soft water ($\leq$ 45 mg/L as $CaCO_3$) which will protect the most sensitive aquatic fauna is .005 mg/L. For porewater (795 mg/L as $CaCO_3$) the recommended safe level is .01 mg/L total lead, although the antagonistic reactions of calcium and/or hardness and complexation might render some fraction of the total non-toxic (Demayo et al. 1980).

There is no suggestion in the literature that was reviewed that stable and radioactive lead isotopes behave differently in a chemical sense, nor that organisms discriminate between them physiologically. Thus, while the environmental behaviour of lead-210 is reviewed preferentially in this section, information on stable lead in freshwater systems has also been used where necessary to bridge data gaps.

The general ecological properties of Pb-210 are: no nutrient analogues; principle exposure modes are through ingestion, inhalation and adsorption; a high degree of food chain transport; a successive food chain concentration of <1 to 10; critical accumulation in kidney and lungs; a moderate degree of assimilation; and a high (in the order of years) biological half-life (Whicker and Schultz 1982).

Recent environmental monitoring programs in the Saskatchewan areas of uranium development have included lead-210 analyses of water, sediments, and aquatic biota from a number of sites. This section relies heavily on the results of those programs because of the apparent lack of other comprehensive studies from elsewhere.

5.1.1 Lead-210 in Fresh Water

Few studies were found which presented lead-210 levels in water, sediments and biota at the same time and place. Some reported values were not useful because they fell below the detection limit of 0.5 pCi/L. Even some of the recent data from the environmental monitoring programs in Saskatchewan can be used only to put an upper limit on distribution expressions. The accurate determination of lead levels in fresh water is complicated by its tendency to concentrate in the water surface microlayer (approximately the upper 0.3 mm), especially when organic materials are present in thin films. In Lake Michigan, the ratio of lead in the surface layer to lead in bulk water samples was 4.8, with most of it being in the form of particles exceeding 45 um diameter (Elzerman 1976, Chester and Stoner 1975 cited by Demayo et al. 1980). Mahon and Mathewes (1983) report lead-210 values for 7 lakes in the Okanagan region of British Columbia. Spring and summer concentrations are given as <0.2 and <0.04 Bq/L (<0.5 and <1.0 pCi/L), respectively. These va'ues are effectively below the limit of detection.

From the Key Lake area of northern Saskatchewan, 113 water samples taken from 1976-1978 had a median concentration of 0.02 Bq/L (0.5 pCi/L) lead-210 (range of <0.02 to 0.4 Bq/L or <0.5 to 10 pCi/L). A series of site specific water samples from the nearby McClean Lake property in 1979-1980 had a median

concentration of 0.05 Bq/L (1.35 pCi/L) lead-210 with a range of <0.02 to 1.6 Bq/L (<0.5 to 44 pCi/L) (Canadian Occidental 1980).

In Great Bear Lake, water samples taken in 1978 at 37 stations in the vicinity of an operating silver mine and an abandoned uranium mine contained less than the detectable limit of lead-210 (<0.004 Bq/L (<0.1 pCi/L)). The water was slightly basic (pH of 7.1 to 7.9) and moderately alkaline, total hardness (55 to 81 mg/L). Under these conditions some high lead levels were found in sediments (up to 3.4×10^5 Bq/kg (9.1×10^5 pCi/kg)) but were evidently immobilized (Moore and Sutherland 1981).

5.1.2 Lead-210 in Freshwater Sediments

Suspended particles in water attract and bind metals and other substances and when settled, immobilize them in bottom sediments. A subsequent change in water quality, such as a reduction in pH or a change in ionic composition may release the bound materials.

There is laboratory evidence that inorganic lead can be methylated to a more toxic organic form by bacterial action in sediments and that the process is dependent on temperature, pH and the microbial population of the aqueous medium, but independent of lead concentrations in the sediment itself (Chan and Dong, 1978 and Chan, 1979, cited by Demayo et al. 1980). While documentation of this process in field conditions was not found, it suggests that total lead levels measured in water may underestimate the bioavailability of lead in food chains leading to man.

The concentration of lead in sediments from several U.S. reservoirs in a lead-mineralized area was positively correlated with the depth of water, organic content and the percentage of clay-size particles (<1 um). In the Great Lakes, the lead

content of sediments also correlated with the percentage of clay and organic content (Demayo et al. 1980). If the TDS level is high, much of the lead can be in the dissolved state rather than settling to the bottom. If humic acids are present, lead can be released back from the sediments (Demayo et al. 1980).

Some useful analyses of lead-210 in sediments are associated with the previously cited water data. The seven Okanagan lakes, for example, had sediment lead-210 concentrations of 0.2 $\pm$ 0.1 and 0.2 $\pm$ 0.2 Bq/g (6.1 $\pm$ 2.7 and 6.3 $\pm$ 5.2 pCi/g) (mean $\pm$ sd) in spring and summer, respectively (Mahon and Mathewes 1983).

From the Key Lake area, 67 sediment samples had a median concentration of 0.2 Bq/g (6.3 pCi/g) (range of <0.004 to 30 Bq/g (<0.1 - 822 pCi/g)). Samples from the McClean Lake study area had a median concentration of 0.1 Bq/g (3.9 pCi/g) dry weight and a range for 29 samples of <0.02 to 0.7 Bq/g (<0.5 to 20 pCi/g) dry weight) (Canadian Occidental 1980).

Analyses of sediments from Key Lake area waters yielded lead-210 activities ranging from 0.18 to 0.20 Bq/g in 1982. Earlier baseline samples from the same general area ranged from 0.02 to 1.8 Bq/g in 1977 and 0.03 to 30.41 Bq/g in 1978 (Key Lake Mining 1983).

Sediment levels of lead-210 ranging from 0.01 to 0.14 Bq/g (wet weight) were found in Milliken and Fredette Lakes (Swanson 1982 and 1984). These are considered to be baseline (unaffected by mining activities) lakes in the area.

5.1.3 Lead-210 in Benthos

Lead is not essential to metabolic processes in benthic invertebrates. As a contaminant, total lead has been measured in

some aquatic animals but few reports could be found of lead-210 concentrations. Benthic feeding organisms may ingest radionuclides with sediment and gut contents can significantly affect whole animal analytical results (Blaylock 1982). However, surface adsorption to exoskeletal structures may also affect whole animal values and obscure the extent of concentration of radionuclides into tissues. The problem was investigated by Swanson (1982) who reported radionuclide levels in insects from the Beaverlodge area of Saskatchewan. The animals were starved in distilled water to clear gut content prior to analysis, but the results were still similar to those from other areas affected by uranium mining and milling, where benthos were not cleared prior to analysis. Control values were like those in insects from uncontaminated U.S. and Finnish waters (Anderson et al. 1963, Kauranen and Miettinen 1970 as cited by Swanson 1982).

The median concentration of lead-210 in filter feeding blackfly larvae from a contaminated stream was 0.804 Bq/g wet (range 0.245 to 1.265 Bq/g) while control area insects had a median value of 0.019 Bq/g wet and a range of 0.008 to 0.082. Predatory dragonfly nymphs from the tailings area had a concentration of 0.014 Bq/g wet and a concentration of 0.033 Bq/g was measured in the control larvae. The latter results are based on small samples but suggest that lead-210 was not being concentrated in the trophic level above the filter feeders (Swanson 1982).

In freshwater clams experimentally exposed to radionuclides, lead-210 was found to move readily across gut membranes and accumulate in the shell to six times the soft tissue level. The chelate stability of lead and other divalent ions appeared to be inversely related to their mobility across membranes and/or tissue accumulation rates (Harrison and Quinn 1972).

5.2 Aquatic Concentration Factors

5.2.1 Distribution Coefficients - Sediment to Water

Limited data were found for water and sediment concentrations at the same time and place. To establish at least an approximate relationship between lead-210 in water and sediment, the most nearly contemporaneous data from waters of the Key Lake area in Saskatchewan were used to calculate distribution coefficients. Table 5.1 gives the results of these calculations for six locations (Key Lake Mining Corporation 1982).

A study from the Beaverlodge area of northern Saskatchewan, yielded some comparable lead-210 data from water, sediments and biota (Swanson 1982). Table 5.2 presents distribution coefficients for sediments from water calculated from those data.

Although these examples were drawn from different geographical areas and different years, the average calculated K_D's are quite similar.

5.2.2 Bioaccumulation Factors

As previously noted, data for lead-210 are scarce. Thompson et al (1972) give a bioaccumulation factor of 100 mL/g for lead in edible aquatic organisms. Since there is basically no discrimination by organisms between stable and radioactive isotopes of the same element Cushing (1970), this BF value has been cited also for lead-210 (Mahon 1982, Canada Wide Mines 1981).

The only recent and discriminating investigation of bioaccumulation factors for lead-210 and other selected radionuclides which could be found is that of Swanson (1982 and 1984). Samples of

could be found is that of Swanson (1982 and 1984). Samples of water sediments, aquatic invertebrates (insects) and fish were obtained from the Beaverlodge area of northern Saskatchewan. The results of analyses of these samples were used to calculate BF's for different feeding groups of benthos. A portion of these results have been reproduced on Tables 5.3 and 5.4.

These concentration factors are based on small samples and variable data and are not regarded as definitive. They indicate a low efficiency of radionuclide transfer from sediments to insects but a more consistent relationship between levels in sediments and insects than between water and insects.

5.3 Deficiences in the Data Base

The deficiencies of the uranium data base listed in Section 2.3 also apply to the data base for lead-210.

TABLE 5.1

LEAD-210 DISTRIBUTION COEFFICIENTS (K_d)

SEDIMENT TO WATER IN THE KEY LAKE AREA

Location	Water		Sed (dry)		K_d
	Date	pCi/L	Date	(pCi/g)	(mL/g dry)
Key Lake N.	6/77	0.5	7/77	4.0	8000
Key Lake S.	8/77	0.7	7/77	1.9	2700
	10/77	2.0	9/77	1.7	900
MacDonald Lake	8/77	0.6	7/77	41.5	6920
	10/77	1.6	10/78	5.1	3200
David Creek	8/78	0.7	9/78	2.8	4000
Kathy Lake	10/77	0.7	9/77	0.55	800
Little MacDonald L	3/77	0.32	7/77	19.4	60600

K_d = 1900 mL/g (dry)
median K_d = 3000 mL/g (dry)
range K_d = 800 to 69200 mL/g (dry)

Ref: Key Lake Mining Corp. 198?

TABLE 5.2

LEAD-210 DISTRIBUTION COEFFICIENTS (K_d)

- SEDIMENT TO WATER IN THE BEAVERLODGE AREA

Location	Mean Water		Mean Sediment			K_D
	Bq/L	(n)	Bq/g(wet)	(n)	% moisture	mL/g (wet)
Beaverlodge L.	0.03	4	1.6	18	73	53,333
Milliken L.	0.04	4	0.08	12	65	2,000
Fredette L.	0.02	4	0.14	12	77	7,000
Tailings System:						
Below 1st L.	3.1	2	1.0	6	13	333
Above $BaCl_2$ Treatment	0.19	2	0.82	6	41	4,100
Below $BaCl_2$ Treatment	0.04	2	0.23	6	41	5,750
Mouth of Creek	0.04	1	0.80	3	30	20,000
Fredette Creek	0.02	1	0.01	9	52	2,000

Ref. Swanson 1984

TABLE 5.3

BIOACCUMULATION FACTORS FOR LEAD-210 FROM WATER TO INSECTS AND SEDIMENT TO INSECTS

Location	Species	Feeding Habits	Water to Insects (mL/g wet)	Sediment to Insects (g/g wet)
below first tailings lake	Blackfly	filter feeders	158	1.29
Above $BaCl_2$ plant	Caddisfly	omnivorous	16,000	0.62
at last point of control	Dragonfly	predators	475	0.05
	Backswimmers	plant fluids & possibly insects	444	0.06
	Damselfly	predators	1,333	0.19
Tailings Creek Mouth	Midge	detritivores	6,471	-
Fredette Creek (Control)	Blackfly	filter feeders	57	2.0
	Dragonfly	predators	49	1.5

Ref: Swanson 1982

TABLE 5.4

BIOACCUMULATION FACTORS FOR SEDIMENT TO INSECTS
FROM TAILINGS AND FREDETTE CREEKS
(RANGES BASED ON STANDARD ERROR OF THE MEAN)

		Sediment							
		Blackflies		Caddisflies		Midge		Dragonflies	
		T*	F*	T	F	T	F	T	F
^{210}Pb	highest	0.44	2.7	0.39	12	0.49	--	0.25	8.9
	mean	0.69	2.0	0.77	8.0	0.36	--	0.17	5.0
	lowest	1.4	1.5	1.5	4.5	0.29	--	0.12	1.8

T = Tailings system
F = Fredette Creek system

Ref: Swanson 1984

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6.0 POLONIUM

Polonium is a radioactive metal belonging to group VIA in the periodic table. It is a component of the uranium decay series and exists in several isotopic forms with half-lives ranging from 3.04×10^{-7} seconds to 138 days. Polonium-210 (half-life of 138 days) is an important natural alpha emitter, one step removed from lead-206, the stable end product of this series (Eisenbud 1973). It is present in nature at very low concentrations (e.g. in igneous rock at 2×10^{-10} ppm) (Bowen 1966), but has the potential for biological impact because of the decay of its longer lived precursor, lead-210 (half-life of 19.4 y). Together with lead-210, it is precipitated from the atmosphere and deposited on vegetation thus entering terrestrial food chains leading to man. In aquatic systems, polonium-210 may be preferentially incorporated over lead-210 by marine organisms, accounting in part for disequilibria observed in marine studies (NRCC 1983). General ecological properties of polonium-210 include: no chemical analogues; principle exposure modes are ingestion, inhalation and adsorption; a high degree of food chain transport, successive trophic level concentration of <1.0 - 10; critical organs are spleen, kidney and lung; moderate degree of assimilation; and a moderate (in the order of weeks) biological half-life (Whicker and Schultz 1982).

6.1 Distribution in the Freshwater Environment

6.1.1 Polonium in Fresh Water

Few data could be found. Mahon (1982) gives a mean polonium value of 0.008 Bq/kg (0.217 pCi/kg) for 77 fresh water samples from the B.C. interior. In waters from northern Saskatchewan, levels of polonium-210 has ranged from 0.004 to 0.3 Bq/L (<0.1 to 8.3 pCi/L) in the McClean Lake area (Canadian Occidental 1980),

and <0.005 to 0.05 Bq/L (<0.135 to 1.35 pCi/L) at Delta Lake (Key Lake Mining 1982).

6.1.2 Polonium in Freshwater Sediments

One set of 16 values of polonium-210 in sediments from the McClean Lake area in Saskatchewan ranged from 0.04 to 0.4 Bq/g (1.0 to 10 pCi/g) (Canadian Occidental 1980). Mahon (1982) gives a mean polonium value of 11 $\pm$ 19 Bq/kg (300 $\pm$ 500 pCi/kg) for 21 sediment samples.

6.1.3 Polonium in Benthos

A single calculated value of 4×10^{-10} ppm for polonium in fresh water invertebrates is given by Thompson et al (1972). This value has been widely cited by subsequent authors.

6.2 Aquatic Bioaccumulation Factors

Insufficient information on polonium distribution in fresh water systems has been found to support a discussion of concentration factors at this time.

Thompson et al (1972) give a derived concentration factor for polonium in marine invertebrates of 2×10^4 and a measured factor of 5×10^3. In freshwater invertebrates, a derived value of 2×10^4 is given. This value has been widely cited.

6.3 Deficiencies in the Data Base

These are almost total and are as outlined in Section 2.3.

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7.0 PRIORITIES FOR THE PHASE II PROGRAM

The review of the currently available information on distribution coefficients and bioaccumulation factors for the key uranium series radionuclides in freshwater benthos presented in Chapter 2 through 6 led to the following conclusions:

1. Very little is known on the behaviour of thorium and polonium-210 in the freshwater-benthos and sediment-benthos chains.
2. Relatively more is known about uranium, radium-226 and lead-210 than the other radionuclides reviewed. However, large gaps exist in the data bases available for all of the radionuclides.
3. Insufficient data is available to assign priorities to the radionuclides on the basis of potential dose to humans. This is due to insufficient information on water-fish-man chains, particularly as they relate to doses in areas affected by uranium tailings management, as well as information gaps in the water-sediment, water-benthos and sediment-benthos chains.
4. At this time, thorium must be ranked as a low priority for the Phase II program due to the fact that environmental concentrations of thorium tend to be below the analytical capability of curently practised sampling and analytical techniques.

The following priorities were chosen for the Phase II field program, based on the deficiencies previously cited in the data bases (Chapters 2 through 6) and the above conclusions:

Program Design

.standard sampling and sample preparation techniques are vital

.sample replication is important at each site

.support data collected should include:

- sediment - texture, % organic content, Fe, Mn
- water - major ions, nutrients, TDS, TSS, trace elements (Ca for radium)
- a general description of lake morphometry or stream size, current and channel characteristics.
- a general description of local hydrology and geology
- confirmation that the benthos are part of a critical pathway
- identification of the benthos to at least the genus level

Data Evaluation

. assign uncertainties to radionuclide concentrations, distribution coefficients and bioaccumulation factors
. critically evaluate applicability of distribution coefficients and bioaccumulation factors
. relate distribution coefficients and bioaccumulation factors back to environmental parameters
. relate distribution coefficients and bioaccumulation factors to invertebrate habitant and trophic niches

8.0 DICTIONARY OF TERMS

Actinide: any element in the series beginning with actinium (atomic number 89) or thorium (90) and ending with atomic number 103

Alpha Radiation: ejection of a helium nucleus (2 protons and 2 neutrons) from the nucleus of an unstable atom; range of a few centimetres of air of 0.04 mm of tissue

Anion: a negatively charged ion

Assimilation: utilization of ingested substances via uptake across biological membranes

Becquerel: 1 disintegration per second (=27.1 pCi)

Benthos: organisms that live on or in the bottom of bodies of water

Beta radiation: ejection of an electron by an unstable atom; range of a few millimetres of plastic or tissue

Bioaccumulation: uptake of substances (natural or introduced) from the surrounding environment by organisms

Biological half life: the amount of time required for one-half of the accumulated body burden of a radionuclide to be excreted

Cation: a positively charged ion

Chemical analogues: elements that behave in similar ways in physical, chemical and biological systems

Colloid: a substance that is too large to pass through a semi permeable membrane, but too small to settle out

Critical accumulation/critical organ: the organ or organs which accumulate the largest quantities of radionuclides and/or which are the most sensitive to radiation

Critical pathway: the food chain contributing the highest potential radiation dose to humans via bioaccumulation

Curie: originally, the amount of radioactivity emitted by 1 g of radium, now defined as 3.7×10^{10} disintegrations per second

Cuticle/exoskeleton/integument: outer covering or tissue of an invertebrate

Detritivores: organisms that feed on dead organic material (detritus)

Disequilibrium: when daughter products of a parent radionuclide (e.g. U-238) are not present in the proportions that occur through decay alone (because of environmental factors such as weathering)

Food chain: the transfer of food from a source such as plants or detritus through a series of organisms with repeated eating and being eaten

Gamma radiation: release of a photon (electromagnetic radiation) by an unstable atom; very penetrating

Hydration: combination of an element or compound with water

Hydrolytic: a tendency to combine with hydroxide (OH^-)

Hypolimnion: the part of a lake below the thermocline (zone of rapid decline in temperature), made up of water that is stagnant and of essentially uniform temperature except during the period of overturn

Isotope: any of two or more species of atoms of a chemical element with the same atomic number and position in the periodic table and nearly identical chemical behaviour but with differing atomic mass number and different physical properties. Synonym of nuclide

Ligand: a group, ion or molecule coordinated to a central atom in a complex

Littoral: an interface zone between the land of a drainage basin and the open water of a lake; the near-shore, shallow zone, often occupied by rooted or floating aquatic plants

"Natural" thorium: the thorium normally found in nature, made up of virtually 100% Th-232

"Natural" uranium: the uranium normally found in nature, made up of 99.28% U-238, 0.0058% U-234 and 0.71% U-235

Niche: the physical space and functional role of an organism in the environment

Omnivores: organisms that feed on a mixture of plant, animal and dead organic material

Oxidation: the loss of one or more electrons from an atom, ion or molecule

Pelagic: the zone of open water; all organisms that live in this zone

Periphytic: plants that grow attached to surfaces, e.g. rocks

Picocurie: 0.037 disintegrations/sec.; 1×10^{-12} Curie

Profundal: sediment zone in a lake below the zone occupied by aquatic plants, algae or phosynthetic bacteria; i.e., exposed, fine sediment free of vegetation of any kind

Radionuclide: an isotope (nuclide) of an element that has an unstable nucleus and therefore decays, giving off radiation

Reduction: the gain of one or more electrons in an atom, ion or molecule

Sorption: to take up and hold by either adsorption (adhesion to surfaces) or absorption (uptake into existing structure)

Total thorium/total uranium: the total amount of all isotopes of thorium or uranium in a substance; this may not correspond to the make-up of "natural" thorium or uranium

Trophic level: the position an organism occupies in a food chain; e.g. an herbivore occupies the second trophic level